5. SUMMARY REPORT ON EFFECTS AT TEMPERATURE, HUMIDITY, AND FUEL-AIR RATIO ON TWO AIR-COOLED LIGHT AIRCRAFT ENGINES

Erwin E. Kempke, Jr.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio

INTRODUCTION

NASA is involved in a research and technology program related to general aviation engines. The overall objective of the program is to establish and demonstrate the technology which will safely reduce general aviation piston-engine exhaust emissions to the levels required by the EPA 1979 emissions standards.

One element of the R&T program is a joint FAA/NASA general aviation piston engine emissions reduction effort. Funded studies are now under way by the two primary engine firms building general aviation piston engines, Avco Lycoming and Teledyne Continental Motors. In phase I of their three-phase programs, each contractor is testing five different engine models to experimentally characterize emissions and to determine the effects of variation in fuel-air ratio and spark timing on emissions levels and other operating characteristics such as cooling, misfiring, roughness, power acceleration, etc. The FAA is using its NAFEC facility to perform independent checks on each of the engines the contractors are testing in phase I. It was recognized early in the program that the phase I tests would be conducted under essentially uncontrolled induction air conditions at widely different geographical locations and that a better understanding of temperature and humidity effects would certainly enhance the ability to make a correlation and better comparison of these data. Therefore, NASA Lewis Research Center has undertaken a series of aircraft engine tests to develop such a correlation. Two engines, identical to ones in the FAA/NASA program, were selected for testing. The engines were from two manufacturers; the first was the Avco Lycoming 0-320-DIAD, four-cylinder, naturally aspirated engine, and the second was the Teledyne Continental TSIO-360, six-cylinder, turbocharged, fuel-injected engine.

This paper presents a brief summary of the results given in two NASA reports (refs. 1 and 2) covering the Avco Lycoming 0-320-D engine testing and the recently obtained results on the Teledyne Continental TSIO-360-C engine.

APPARATUS AND PROCEDURE

Test Facility and Engines

The aircraft engine is shown photographically on the test stand in figure 5-1. The engine was coupled to a 300-horsepower dynamometer through a fluid coupling in the drive shaft which was located under a safety shield. Engine cooling and induction air were supplied by a laboratory air distribution system. The cooling and induction air system can be controlled to deliver air to the engine over a temperature range of 50° to 120° F and over a range of relative humidity from 0 to 80 percent. The cooling air was always at the same conditions as the induction air and directed down over the engine by an air distribution hood. This hood was the same as that which was used by the engine manufacturer in their engine testing. The engine cooling air was removed from the test cell by a high capacity, facility altitude exhaust system which had the inlet located beneath the engine. An additional cell exhaust fan was used to maintain a slightly negative pressure in the test cell. This was done to vent any combustible or toxic gases which may have been present in the test cell during engine operation.

The Avco Lycoming 0-320-D engine exhaust was manifolded together in a standard configuration with the emission sample probe located about 4 feet downstream of the manifold. The exhaust was then ducted out the cell through the roof. Care was taken to insure that the exhaust system was leakproof. A leakproof system was necessary to prevent air dilution of the gas sample which would result in erroneous emission measurements. Bellows were installed over the slip joints of the TSIO-360-C engine exhaust system so as to eliminate air entering the system at the low power conditions.

Instrumentation

A complete description of the instrumentation used in the engine testing is contained in reference 1. All 100 channels of instrumentation were connected to the CADDE (Central Automatic Digital Data Encoder) central data acquisition system and the data were processed on a 360/67 timing-sharing computer.

Numerous modifications were made early in the project to the emissions analyzer instrumentation. In fact, an examination of facility problems disclosed that in the early stages of the project a very large percentage was related to the emissions analyzer. The widespread problem in NO_x measurement at high levels of CO was revealed and solved by modifying the chemiluminescent NO analyzer (ref. 3). However, it is significant to also mention that in the last 9 months there have been very few analyzer problems. The initial concerted effort appears to have resulted in modifying the analyzer into a reliable and accurate instrument.

DISCUSSION OF O-320-D AIR TEMPERATURE AND HUMIDITY EFFECTS FOR SEVEN-MODE CYCLE TEST

Test Procedure

The engine testing procedure was conducted as specified by the Environmental Protection Agency in the Federal Register, vol. 38, no. 136, dated Tuesday, July 17, 1973 (ref. 4) except for the separation of the idle and taxi time in and out modes as shown in the following table:

Mode	Mode description	Power level, percent	Speed, rpm	Time in mode, min
1	Idle out	--	600	1.0
2	Taxi out	--	1200	11.0
3	Takeoff	Full power	2700	.3
4	Climb	80	2430	5.0
5	Approach	40	2350	6.0
6	Taxi in	--	1200	3.0
7	Idle in	--	600	1.0

Prior to the start of a 7-mode cycle (LTO) test, the engine was warmed at 2000 rpm for approximately 10 minutes until all parts were temperature stabilized and all cylinder head temperatures were at least 300° F.

The 7-mode emission cycle data tests were conducted over a range of air temperatures and relative humidities. The induction air and cooling air temperatures were the same and were held at nominal values of 50°, 59°, 70°, 80°, 90°, and 100° F at relative humidities of 0, 30, 60, and 80 percent. For each test condition three LTO 7-mode cycles were run at the full rich fuel-air ratio. This procedure resulted in approximately 450 different engine test conditions.

Seven-Mode Cycle Test Results

Figures 5-2 and 5-3 summarize the CO, NO_x, and HC emissions generated over the 7-mode cycle for each of the four values of relative humidity as a function of air temperature and expressed as a percent of the EPA standards.

In general, the data show that the quantity of emissions produced is strongly affected by the relative humidity, and that this effect increases with increasing induction air temperature. The HC and CO emissions increase considerably at the higher values of air temperature and relative humdity, while at the same conditions the NO_x emissions show a significant decrease. A comparison of the temperature and humidity test results at 100° F and 80 percent humidity to those at 50° F and 0 percent humidity show that, with the increased temperature and humidity, the CO increases by a factor of 1.6, the HC increases by a factor 2.2, and the NO_x decreases by a factor 3.5.

Present-day aircraft engines do not use a temperature-density compensated fuel system. The change in the exhaust emission is primarily the result of richer fuel-air ratios which occur at the higher air temperatures and relative humidities. This is due to the decrease in air density with increased temperatures and the volume of air that is displaced by water vapor in the fuel-air mixtures.

DISCUSSION OF O-320-D AND TSIO-360-C AIR TEMPERATURE AND HUMIDITY EFFECTS AT VARIOUS FUEL-AIR RATIOS ON A PER MODE BASIS

In the preceding section it was stated that the major factor affecting the level of emissions was the fuel-air ratio which occurs at the particular ambient condition. It is also known that an ambient condition can affect the induction vaporization and basic combustion process, thereby influencing the HC and NO_x emissions. Therefore, a series of tests was performed to establish the effect of air temperature and relative humidity at various fuel-air ratios on a per mode basis (idle, taxi, takeoff, climb, and approach). The test conditions include varying the fuel-air ratio for each of the five emissions test modes over the following range of ambient conditions: air temperature (°F), 50, 59, 80, and 100; relative humidity (percent), 0, 30, 60, and 80. Combinations of these parameters with the modes over a range of fuel-air ratios resulted in over 800 different test conditions. These data can be used to provide a variety of fuel schedules for the individual modes over a range of ambient conditions which can be used to correlate ambient conditions and emissions. The data can also be used to construct optimum baseline cycles based on leaner fuel schedules; the data thereby provide a quick and simple method for assessing the benefit of tailored fuel schedules.

The results of the per mode tests indicate that for a fixed fuel-air ratio the effect of temperature and humidity on the HC and NO_x exhaust emissions at the higher temperature and relative humidities was significant, whereas the CO exhaust emissions are essentially independent of ambient conditions. At a fixed fuel-air ratio with higher air temperatures and relative humidities, the HC emissions increased and the NO_x emissions decreased in certain modes.

Figures 5-4 to 5-18 summarize for the Avco Lycoming O-320-D engine the CO, NO_x, and HC modal emissions generated over a range of fuel-air ratios for the ambient conditions (50° F and 0 percent humidity, and 100° F and 80 percent relative humidity). The HC emissions (shown in figs. 5-5, 5-8, 5-11, 5-14, and 5-17) were higher especially for the climb, taxi, and idle modes at the high temperature and relative humidity condition. The NO_x emissions (shown in figs. 5-6, 5-9, 5-12, 5-15, and 5-18) decrease for the takeoff, climb, and approach modes at the higher temperature and relative humidity conditions. This decrease was more pronounced at the leaner fuel-air ratios. The CO emissions (shown in figs. 5-4, 5-7, 5-10, 5-13, and 5-16) are independent of ambient conditions with the exception of the climb mode, which indicates a very slight effect.

The previously mentioned trends of increasing HC and decreasing NO_x exhaust emissions at the higher temperature and humidity conditions are attributed to the volume of moisture in the induction air, which can affect the combustion process and the vaporization characteristics of the fuel.

A comparison of the previously discussed 7-mode cycle results with a similar constructed seven-mode cycle using the individual modes lean-out data showed reasonably good agreement.

Shown in figures 5-19 to 5-27 for the takeoff, climb, and approach modes are comparisons of the TCM TSIO-360-C engine and the Avco Lycoming O-320-D engine temperature-humidity lean-out tests for the two extreme ambient test conditions of 50° F and 0 percent relative humidity, and 100° F and 80 percent relative humidity.

In general, the results of testing a naturally aspirated carbureted engine and a fuel-injected turbocharged engine show similar emission trends with changing temperature and humidity as the fuel-air ratio is changed. One exception occurred at the takeoff mode in which very little humidity effect on NO_x formation was observed for the TSIO-360 engine, whereas a significant effect was seen for the O-320-D engine.

CONCLUDING REMARKS

The results reported herein are based on tests conducted on one carbureted naturally aspirated engine (testing completed) and one turbocharged fuel-injected engine (testing still in progress). A great deal of additional analysis of the data is required to develop a correlation that would relate emissions to the temperature-humidity conditions. Although the results thus far are encouraging that such a correlation can be derived, it is not certain that one "universal" correlation based on only two engine types can be developed to cover the broad spectrum of engine models or classes produced today.

The following remarks are on what is viewed as hopefully a more direct and practical solution to the problem. NASA's test results to date have shown that temperature and humidity effects must be considered by those involved in setting regulations designed to insure the compliance with the emissions standards. Standard day conditions need to be specified and required for compliance testing. Although NASA does not at this time have a strong recommendation, it would seem that a temperature of 59° F would be a logical selection inasmuch as this is a standard value used in engine performance correction calculations. A pressure of 29.92 inches of mercury and a relative humidity of 0 to 10 percent might be acceptable for the same reasons. NASA's results as previously discussed have shown that the hunidity effects at a temperature such as 59° F are insignificant; therefore, the humidity value selected should not be critical. Once the standard day conditions are specified, it is likely that modifications would have to be made to the emissions test stands so that one could conduct any further testing at these conditions.

REFERENCES

1. Meng, Phillip R.; Skorobatckyi, Michael; Cosgrove, Donald V.; and Kempke, Erwin E.: Emissions of an Avco Lycoming 0-320-DIAD Air-Cooled Light Aircraft Engine as a Function of Fuel-air Ratio, Timing, and Air Temperature and Humidity. NASA TM X-73500, 1976.

2. Skorobatckyi, Michael; Cosgrove, Donald V.; Meng, Phillip R.; and Kempke, Erwin E.: Effect of Air Temperature and Relative Humidity at Various Fuel-Air Ratios on Exhaust Emissions on a Per-Mode Basis of an Avco Lycoming 0-320-DIAD Light Aircraft Engine. NASA TM X-73507, 1976.

3. Summers, Robert: NO_x Destruction by CO in NO_x to NO Converters of Chemiluminescence NO Analyzers. NASA TM X-73480, 1976.

4. Control of Air Pollution From Aircraft and Aircraft Engines. Fed. Register, vol. 38, no. 136, pt. II, July 1973, pp. 19088-19103.

DISCUSSION

Q - W. Westfield: Was the cooling airflow supplied to the engine held constant or did it vary with the induction air temperature?
A - E. Kempke: The induction and cooling airflow were at the same temperature-humidity conditions.

COMMENT - E. Becker: We were privy to the O-320 engine data from NASA. As a result, I ran some comparison plots using our IO-360 engine NAFEC data to determine if this data lined up with NASA's data. For the CO pollutant, I got very similar trend curves. At selected temperature and humidity conditions the curves closely matched NASA's. They exhibited the same type of split characteristics as the NASA curves. Also, I noticed that apparently there is some characterization required because if one just relies on the low powered engines to define the shape of the curve one may end up getting slightly erronous results at higher power levels. Both the NASA TSIO-360 data and the NAFEC IO-360 data indicate that the higher powered engines do shift the characteristic shape of the curve a little higher. So I think some additional assessment is required to come up with an optimization type correction factor that takes all of these engine characteristics into consideration.

Q - E. Kempke: Is that conclusion based on making the comparison on a pound per mode basis.
A - E. Becker: Yes.

COMMENT - E. Kempke: Certainly we must look at other parameters in developing a correlation. The pound per mode parameter was originally selected because it is used by everyone when generating cycle data from leanout data. However, there is some preliminary evidence which shows better parameters may exist. NASA does plan to explore this further.

Q - B. Rezy: Have you taken this leanout data and applied it to a cycle in the two extremes just to see how bad the final answer is according to the EPA standards?
A - E. Kempke: A comparison of using leanout data to generate cycle data with the actual cycle data shows fairly good agreement.

Q - B. Rezy: Were those points taken at the same fuel-air ratios?
A - E. Kempke: Yes. In other words, we looked at the per cycle data, and, using the same measured fuel-air ratio values, we went to the leanout curves to find the pound per mode value. Finally, the pound per mode values for all seven modes were summed to generate the cycle.

Q - W. Westfield: Are you saying you really plugged in the effect of taxi/idle out versus taxi/idle in?
A - E. Kempke: We used the taxi-out fuel-air ratio and the taxi-in fuel-air ratio with the appropriate mode time.

Q - F. Monts: Were the leanout runs done on a fixed throttle basis or were they done on a fixed power basis?
A - E. Kempke: The tests conducted at Lewis were with a dynamometer and therefore were run at a constant power condition for each mode with one exception. The exception occurred during the 0-320 engine testing, where the takeoff power fell off at the 100° F and 80 percent relative humidity condition.

Q - F. Monts: In that case, the data would be of interest for reasons other than emissions such as for power and humidity corrections. Did you try to maintain constant head temperature or did you maintain a constant cooling air flow?
A - E. Kempke: A constant delta pressure was maintained across the engine. Plots that show the variation in the cylinder head temperature and the exhaust gas temperature as fuel-air ratio is varied are available for the TSIO-360-C engine tests.

Q - F. Monts: Did you make any attempt to measure the cooling air mass flow?
A - E. Kempke: Yes, we do measure the cooling airflow.

Q - G. Kittredge: We have responded to one of NASA's recommendations concerning the specifying of a standard reference day. A package of technical amendments, which included a reference day specification, went to the Federal Register the middle of last week. The conditions are temperature of 59° F, relative humidity of 60 percent, and pressure of 29.92 inches of mercury. One of NASA's recommendations concerns correcting data to a standard day and another concerns conducting the testing at standard day conditions. These are two different ways at going at the same thing. Which approach does NASA prefer at this point?
A - E. Kempke: I think the most direct approach is to run the test at standard day conditions; then, no correction factor is needed.

Q - G. Kittredge: This is going to involve fairly expensive laboratory modifications in some areas is it not?
A - E. Kempke: I don't think so, but I must defer to the engine manufacturers to comment on the cost.
A - S. Jedrziewski: Speaking for AVCO Lycoming on the temperature correction factors, I see no need to duplicate elaborate test equipment if a good correction factor can be established. So, Lycoming prefers to do it on a correction factor basis after we have them for all engines we produce.

Q - E. Kempke: Are you saying you'll do that and in your compliance testing use those particular calibration curves for each engine to correct the compliance data?
A - S. Jedrziewski: We are not saying that AVCO Lycoming specifically will do it, we are just saying that probably with the aid of NASA or some other agency those correction factors could be established.

COMMENT - L. Helms: I think what you're saying is that we have no choice - that's the only way to do it.

COMMENT - B. Rezy: With the relative humidity variation that we know we have now in Mobile we honestly feel we cannot come up with a correction factor. Based on what Pete Kempke has presented today, there would be an enormous amount of testing required to find out for all these engines what kind of corrections factors we're really talking about. I don't see that we really have a choice but to try to control relative humidity and temperature.

COMMENT - K. Stuckas: Just as an addendum to what Bernie Rezy said. We are currently looking into purchasing equipment that will do that. We think we found a suitable unit which is produced by Environmental Techtonics and costs $34,000. It controls humidity, temperature, and pressure, and it is a self-contained unit having the capability right now of handling 300 horsepower engines. It can be boosted to handle engines of higher horsepower and the equipment is available right now.

Q - W. Westfield: We're in the R&D end and I'd like to hear from somebody else about whether the engine manufacturers do have the capability of setting actual temperature and humidity. Would this be carried through in a certification process for the airframe itself? What would you do when you tested the airplane outside?

A - B. Rezy: We will be discussing this later today. One of the things that we found very detrimental to leaning out these engines was the acceleration problem in taxi, idle, and approach. One of the advantages we see with having this humidity equipment is the ability to hold temperature and humidity and being able to change it whenever we want to find exactly what fuel-air ratios our fuel injection systems can hold. In the long run this is going to save a lot of flight testing problems.

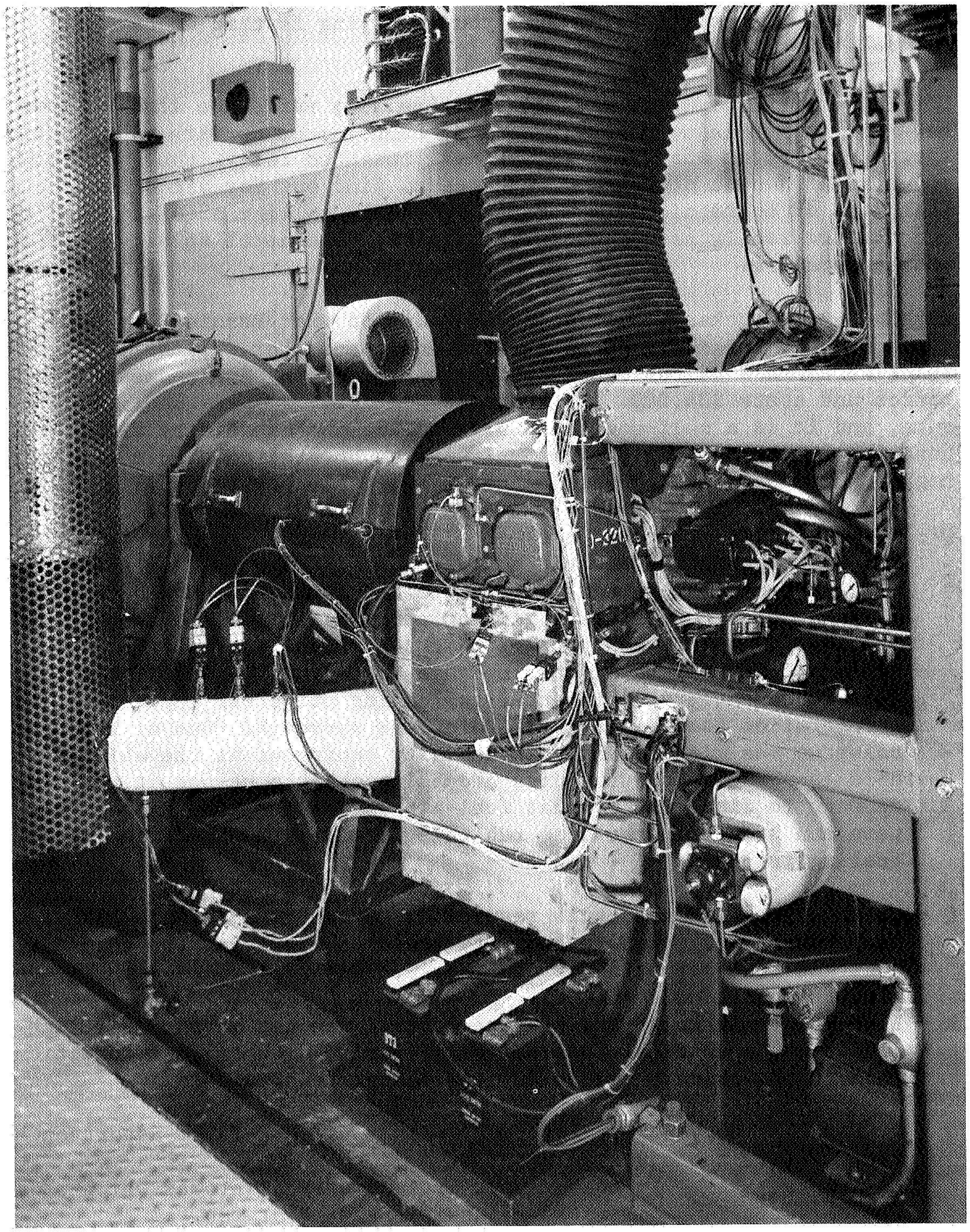
Q - D. Powell: Were the cycle results of CO and HC emissions versus air temperature and relative humidity based on operating the engine at a constant fuel-air ratio or did the fuel-air ratio vary with the particular condition?

A - E. Kempke: Although the mixture control was set in the fuel rich condition, the actual fuel-air ratio varied with ambient conditions; this is the primary reason for the change in emissions.

Q - D. Powell: Do you have information in your TM X-73500 report on how the fuel-air ratio varied?

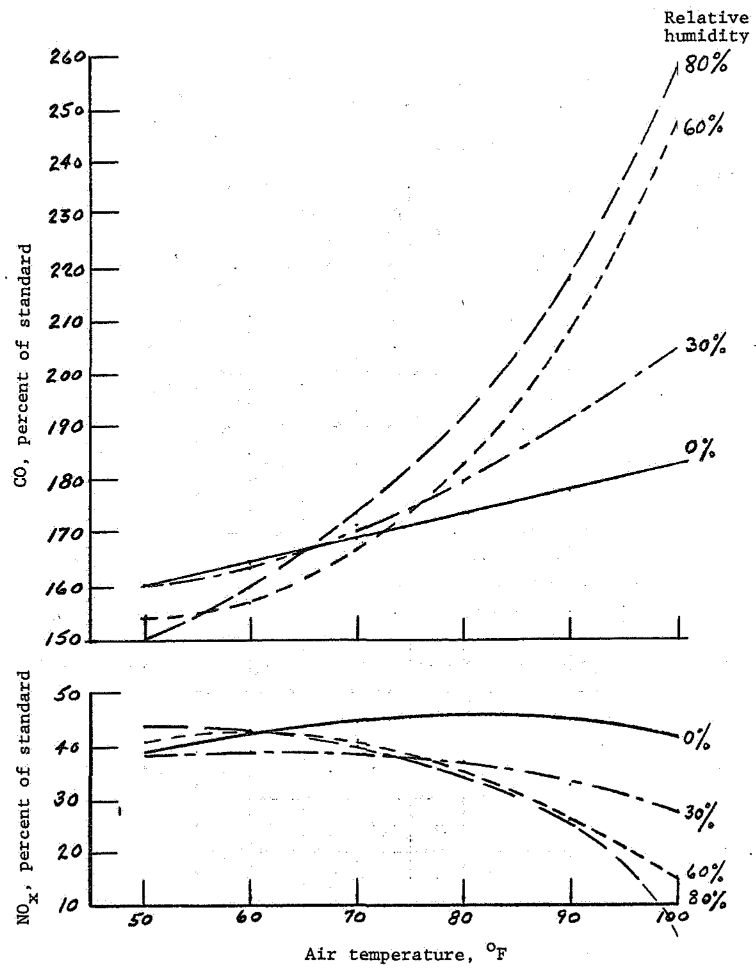
A - E. Kempke. Yes. In that report are computer printouts which show the measured fuel-air ratio values for each test run.

NASA
C-75-2985



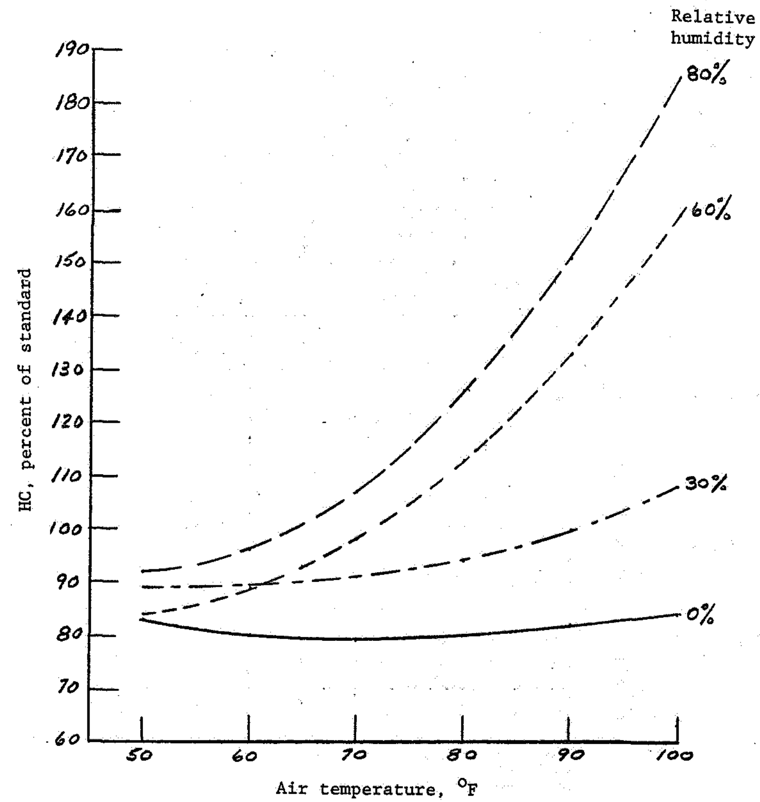
Engine test stand

Figure 5-1



Summary plot of carbon monoxide and oxides of nitrogen with air temperature and relative humidity.

Figure 5-2



Summary plot of hydrocarbon emissions with air temperature and relative humidity.

Figure 5-3

NASA LEAN-OUT DATA

TEMP. 50°F REL. HUM. 0%

TEMP. 100°F REL. HUM. 80%

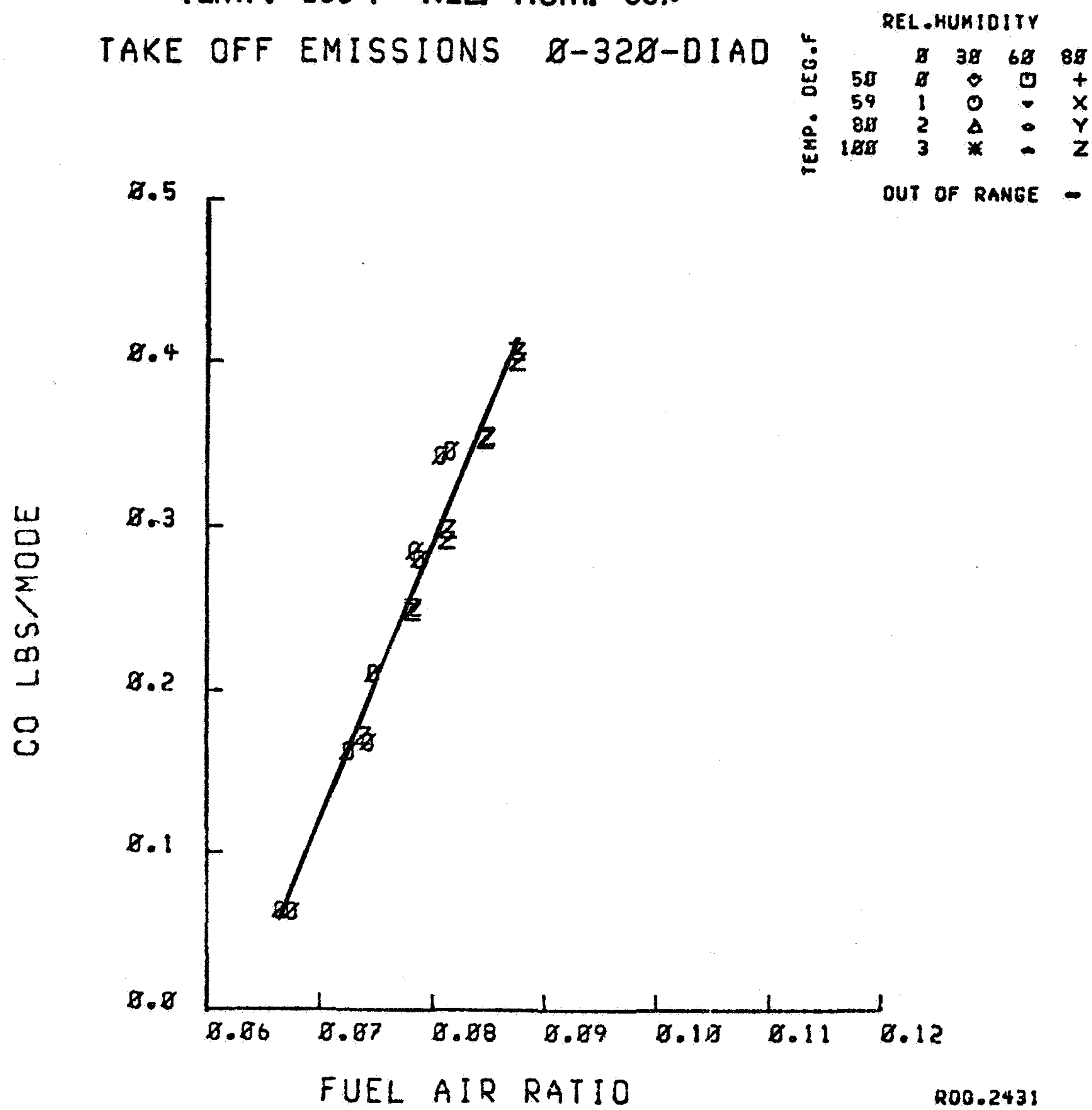


Figure 5-4

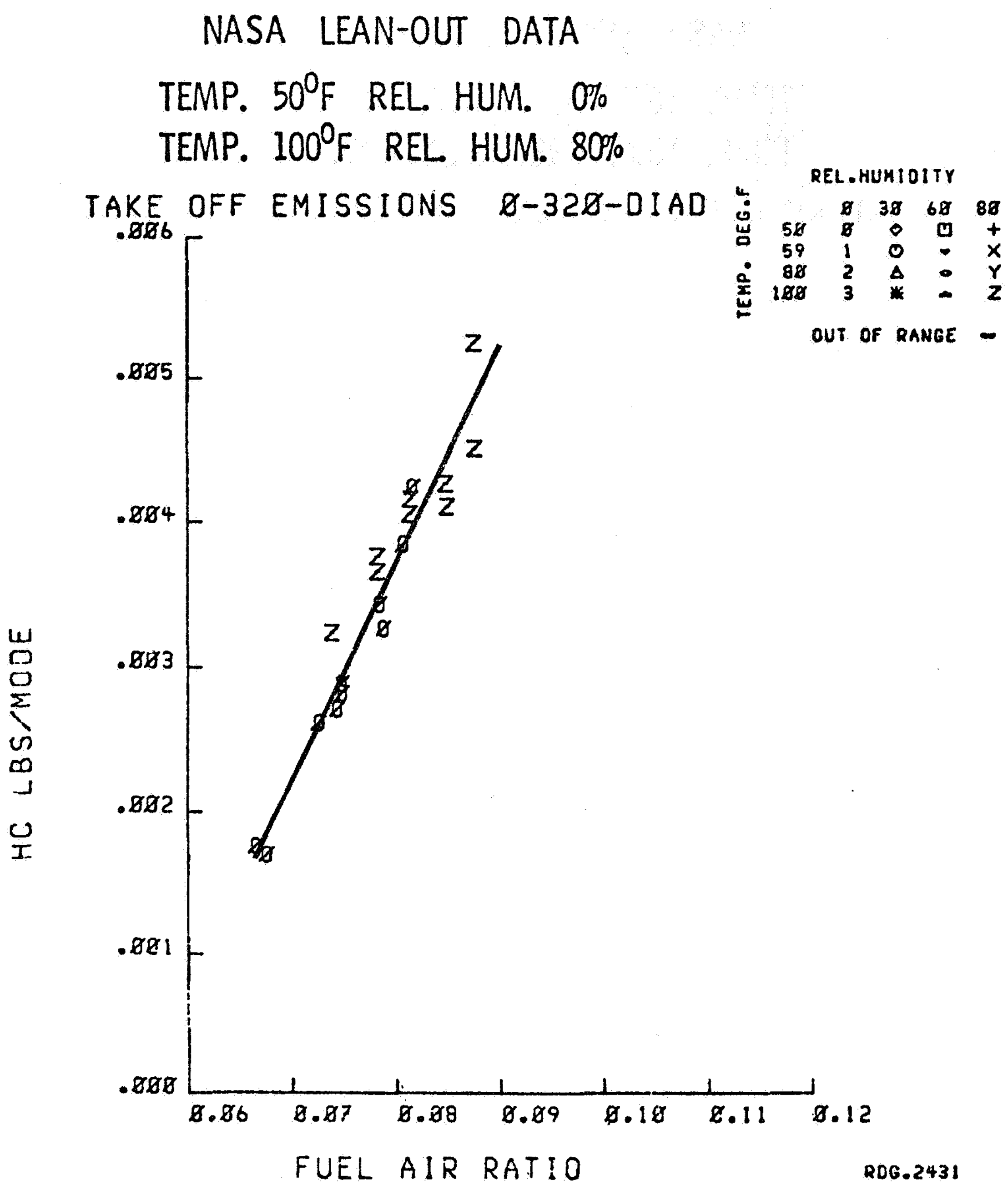

NASA LEAN-OUT DATA
TEMP. 50°F REL. HUM. 0%
TEMP. 100°F REL. HUM. 80%
TAKE OFF EMISSIONS Ø-32Ø-DIAD
REL.HUMIDITY
TEMP. DEG.F
Ø 3Ø 6Ø 8Ø
5Ø Ø ◇ □ +
59 1 O X
8Ø 2 △ Y
1ØØ 3 ✱ Z
OUT OF RANGE
HC LBS/MODE
.ØØ6
.ØØ5
.ØØ4
.ØØ3
.ØØ2
.ØØ1
.ØØØ
Ø.Ø6
Ø.Ø7
Ø.Ø8
Ø.Ø9
Ø.1Ø
Ø.11
Ø.12
FUEL AIR RATIO
RDG.2431

Figure 5-5

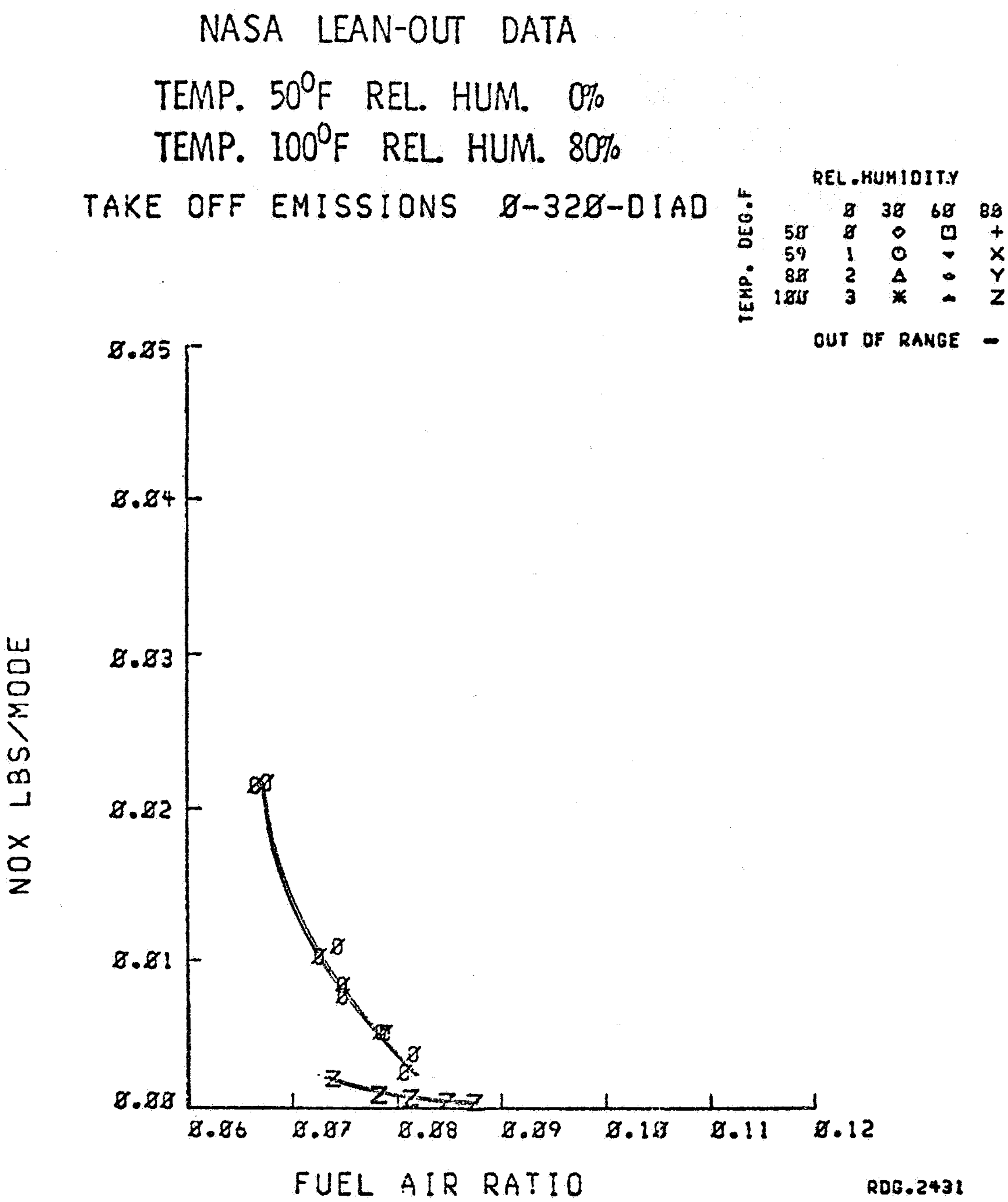

NASA LEAN-OUT DATA
TEMP. 50°F REL. HUM. 0%
TEMP. 100°F REL. HUM. 80%
TAKE OFF EMISSIONS Ø-32Ø-DIAD
REL.HUMIDITY
TEMP. DEG.F
Ø 3Ø 6Ø 8Ø
5Ø Ø ◇ □ +
59 1 O ◆ X
8Ø 2 Δ • Y
1ØØ 3 ✱ ▲ Z
OUT OF RANGE
NOX LBS/MODE
Ø.Ø5
Ø.Ø4
Ø.Ø3
Ø.Ø2
Ø.Ø1
Ø.ØØ
Ø.Ø6
Ø.Ø7
Ø.Ø8
Ø.Ø9
Ø.1Ø
Ø.11
Ø.12
FUEL AIR RATIO
RDG.2431

Figure 5-6

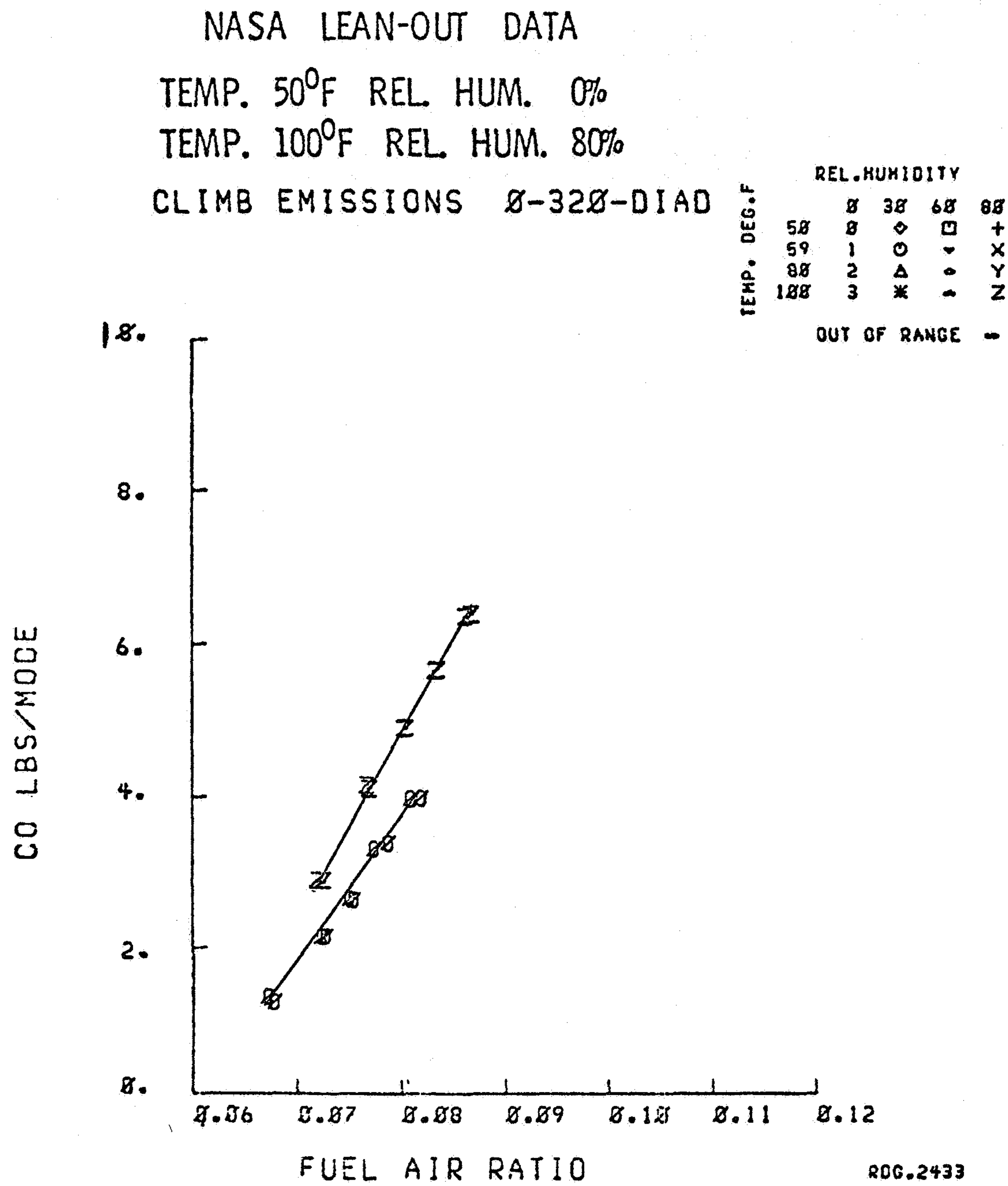

NASA LEAN-OUT DATA
TEMP. 50°F REL. HUM. 0%
TEMP. 100°F REL. HUM. 80%
CLIMB EMISSIONS Ø-32Ø-DIAD
REL.HUMIDITY
TEMP. DEG.F
Ø 3Ø 6Ø 8Ø
5Ø Ø ◇ □ +
59 1 O X
8Ø 2 Δ Y
1ØØ 3 ✱ Z
OUT OF RANGE
CO LBS/MODE
FUEL AIR RATIO
RDG.2433

Figure 5-7

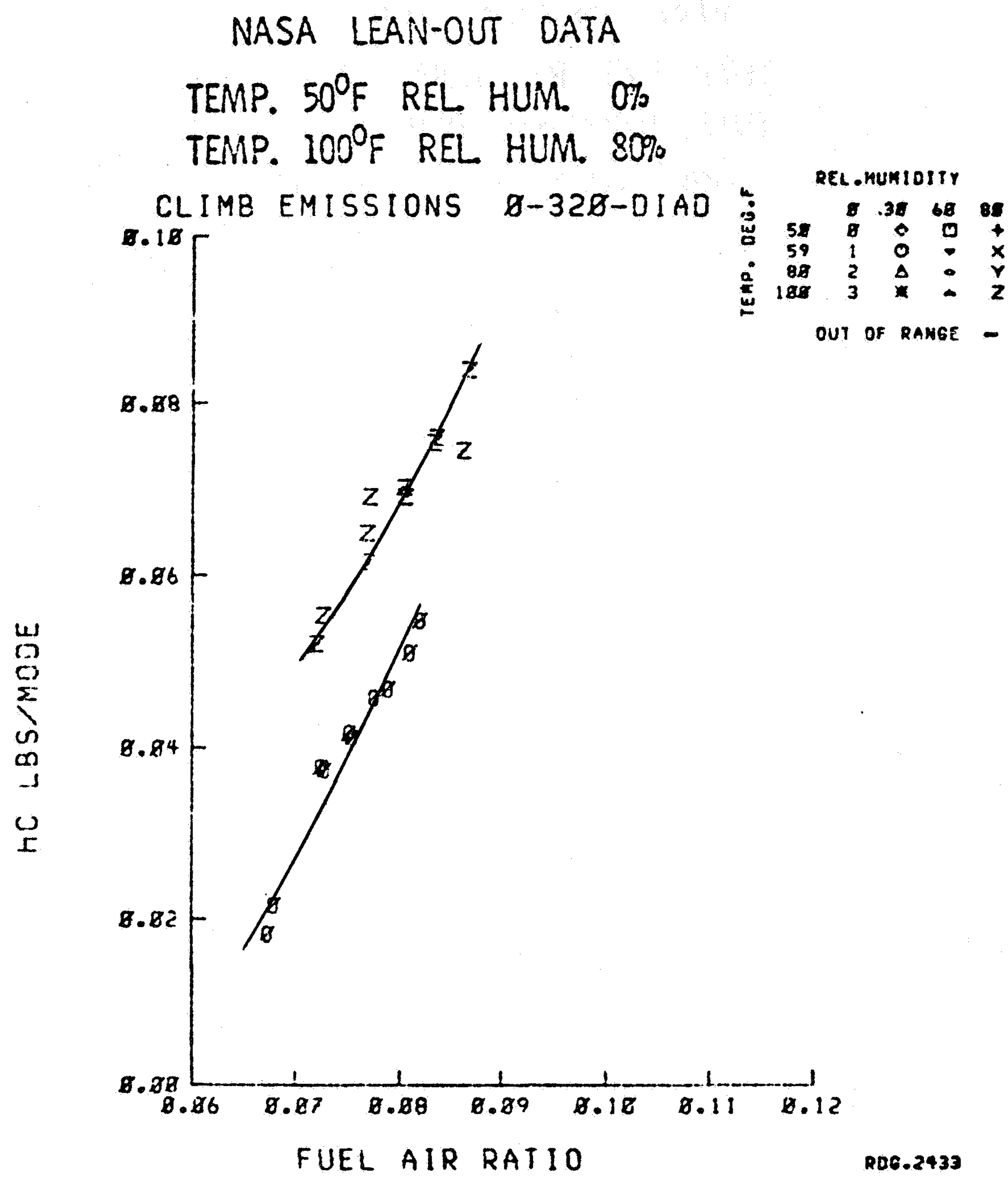
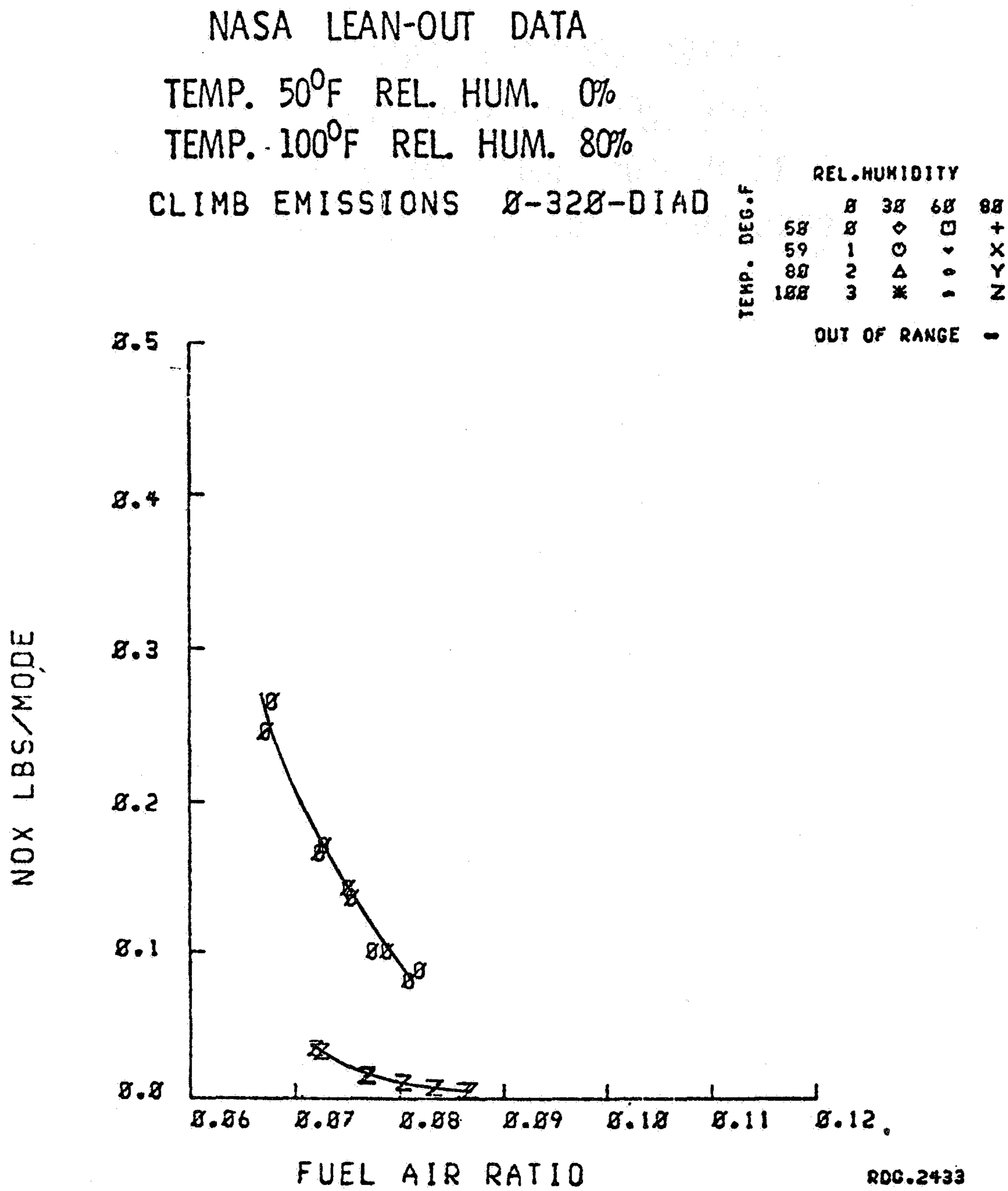

NASA LEAN-OUT DATA
TEMP. 50°F REL. HUM. 0%
TEMP. 100°F REL. HUM. 80%
CLIMB EMISSIONS Ø-32Ø-DIAD
REL.HUMIDITY
TEMP. DEG.F
Ø .3Ø 6Ø 8Ø
5Ø Ø
59 1
8Ø 2
1ØØ 3 Z
OUT OF RANGE
Ø.1Ø
Ø.Ø8
Ø.Ø6
Ø.Ø4
Ø.Ø2
Ø.ØØ
HC LBS/MODE
Ø.Ø6 Ø.Ø7 Ø.Ø8 Ø.Ø9 Ø.1Ø Ø.11 Ø.12
FUEL AIR RATIO
RDG.2433

Figure 5-8



NASA LEAN-OUT DATA
TEMP. 50°F REL. HUM. 0%
TEMP. 100°F REL. HUM. 80%
CLIMB EMISSIONS Ø-32Ø-DIAD
REL.HUMIDITY
TEMP. DEG.F
Ø 3Ø 6Ø 8Ø
5Ø Ø ◇ □ +
59 1 ○ X
8Ø 2 △ Y
1ØØ 3 ✱ Z
OUT OF RANGE
Ø.5
Ø.4
Ø.3
Ø.2
Ø.1
Ø.Ø
NOX LBS/MODE
Ø.Ø6 Ø.Ø7 Ø.Ø8 Ø.Ø9 Ø.1Ø Ø.11 Ø.12
FUEL AIR RATIO
RDG.2433

Figure 5-9

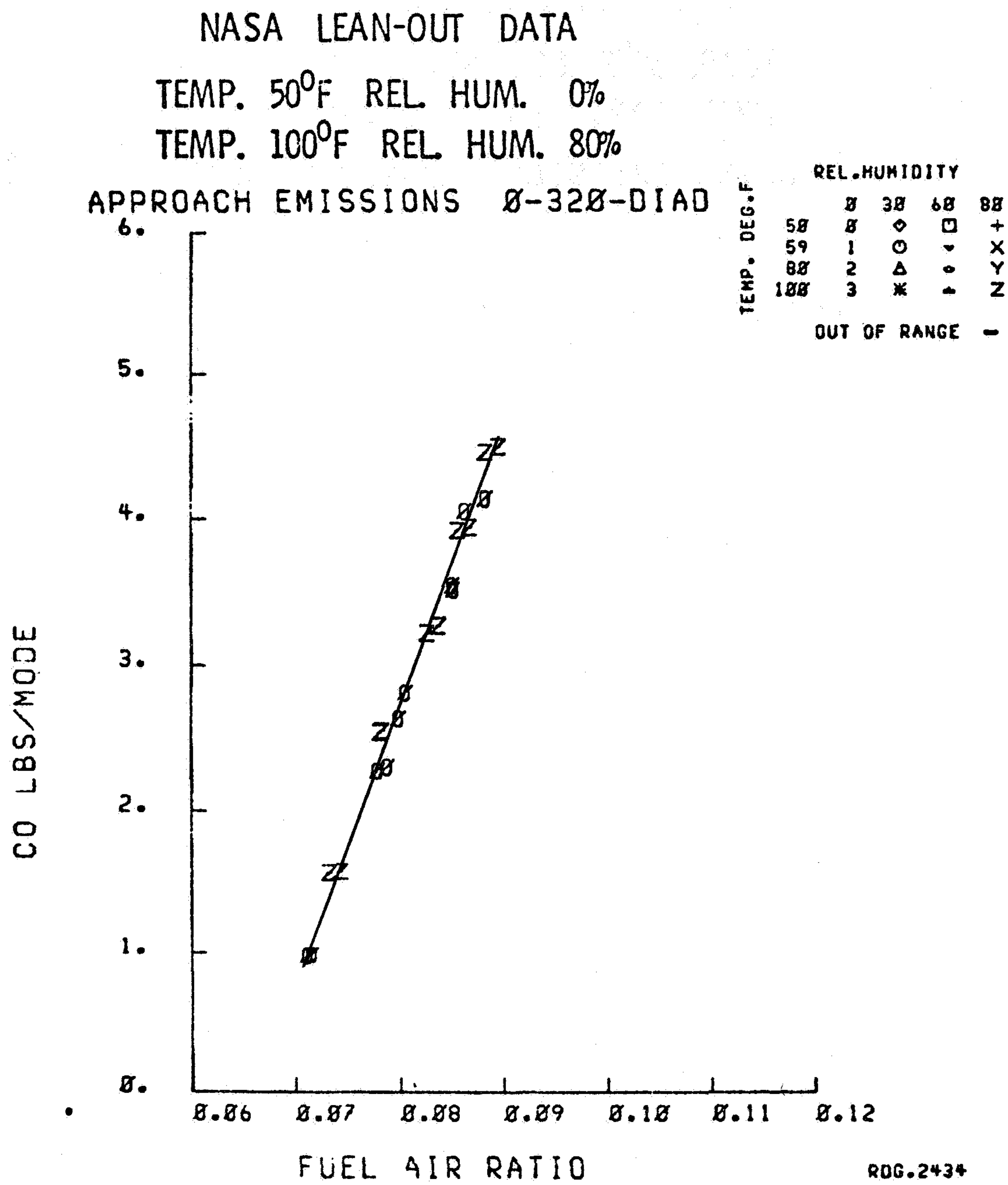
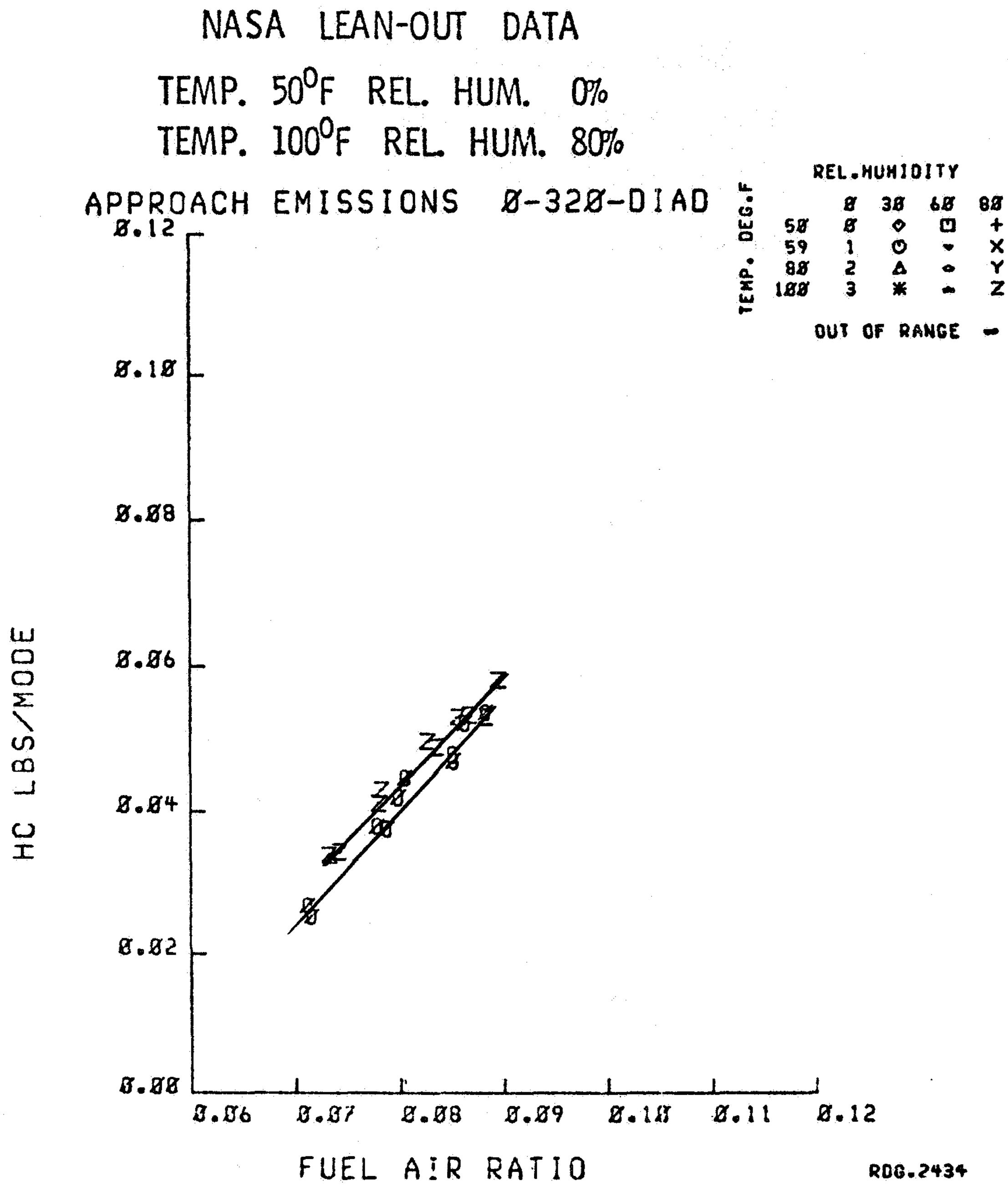

NASA LEAN-OUT DATA
TEMP. 50°F REL. HUM. 0%
TEMP. 100°F REL. HUM. 80%
APPROACH EMISSIONS Ø-32Ø-DIAD
REL.HUMIDITY
TEMP. DEG.F
Ø 3Ø 6Ø 8Ø
5Ø
59
8Ø
1ØØ
OUT OF RANGE
CO LBS/MODE
6.
5.
4.
3.
2.
1.
Ø.
Ø.Ø6 Ø.Ø7 Ø.Ø8 Ø.Ø9 Ø.1Ø Ø.11 Ø.12
FUEL AIR RATIO
RDG.2434

Figure 5-10



NASA LEAN-OUT DATA
TEMP. 50°F REL. HUM. 0%
TEMP. 100°F REL. HUM. 80%
APPROACH EMISSIONS Ø-32Ø-DIAD
REL.HUMIDITY
TEMP. DEG.F
Ø 3Ø 6Ø 8Ø
5Ø Ø ◇ □ +
59 1 ○ X
8Ø 2 △ Y
1ØØ 3 ✱ Z
OUT OF RANGE
HC LBS/MODE
Ø.12
Ø.1Ø
Ø.Ø8
Ø.Ø6
Ø.Ø4
Ø.Ø2
Ø.ØØ
Ø.Ø6 Ø.Ø7 Ø.Ø8 Ø.Ø9 Ø.1Ø Ø.11 Ø.12
FUEL AIR RATIO
RDG.2434

Figure 5-11

NASA LEAN-OUT DATA

TEMP. 50°F REL. HUM. 0%

TEMP. 100°F REL. HUM. 80%

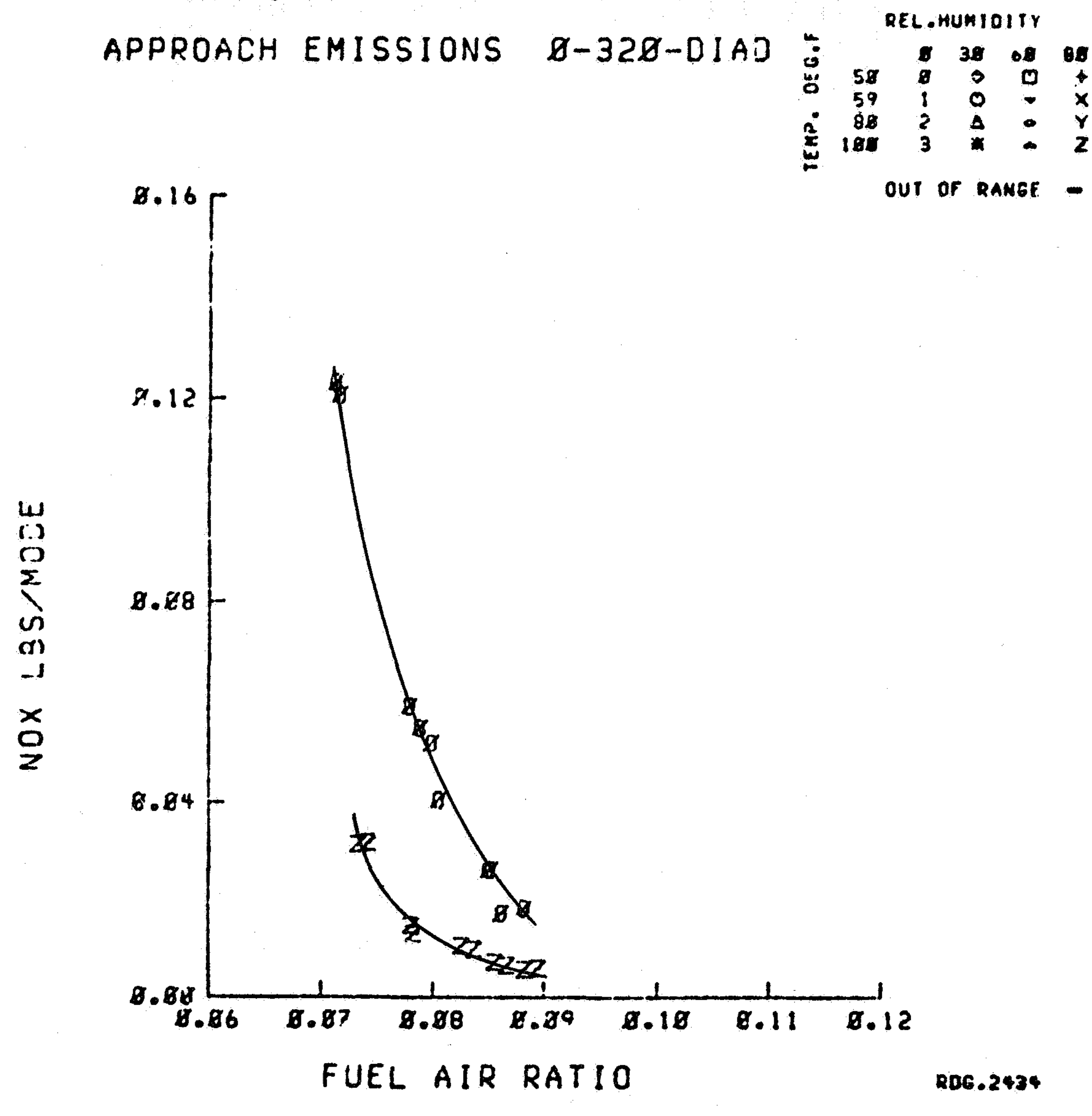
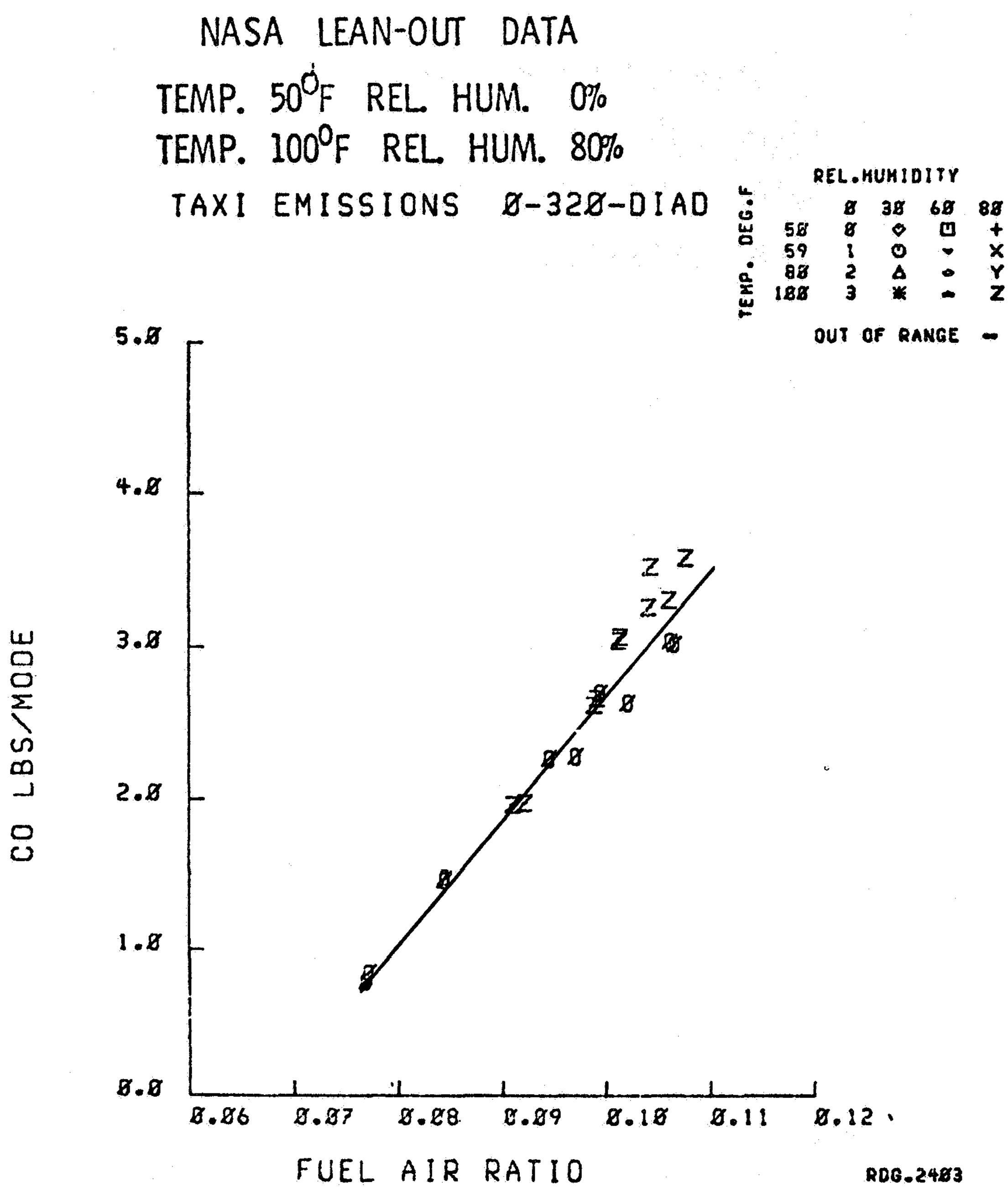


Figure 5-12



NASA LEAN-OUT DATA
TEMP. 50°F REL. HUM. 0%
TEMP. 100°F REL. HUM. 80%
TAXI EMISSIONS Ø-32Ø-DIAD
REL.HUMIDITY
TEMP. DEG.F
Ø 3Ø 6Ø 8Ø
5Ø Ø ◇ □ +
59 1 O X
8Ø 2 Δ Y
1ØØ 3 * Z
OUT OF RANGE
5.Ø
4.Ø
3.Ø
2.Ø
1.Ø
Ø.Ø
CO LBS/MODE
Ø.Ø6 Ø.Ø7 Ø.Ø8 Ø.Ø9 Ø.1Ø Ø.11 Ø.12
FUEL AIR RATIO
RDG.24Ø3

Figure 5-13

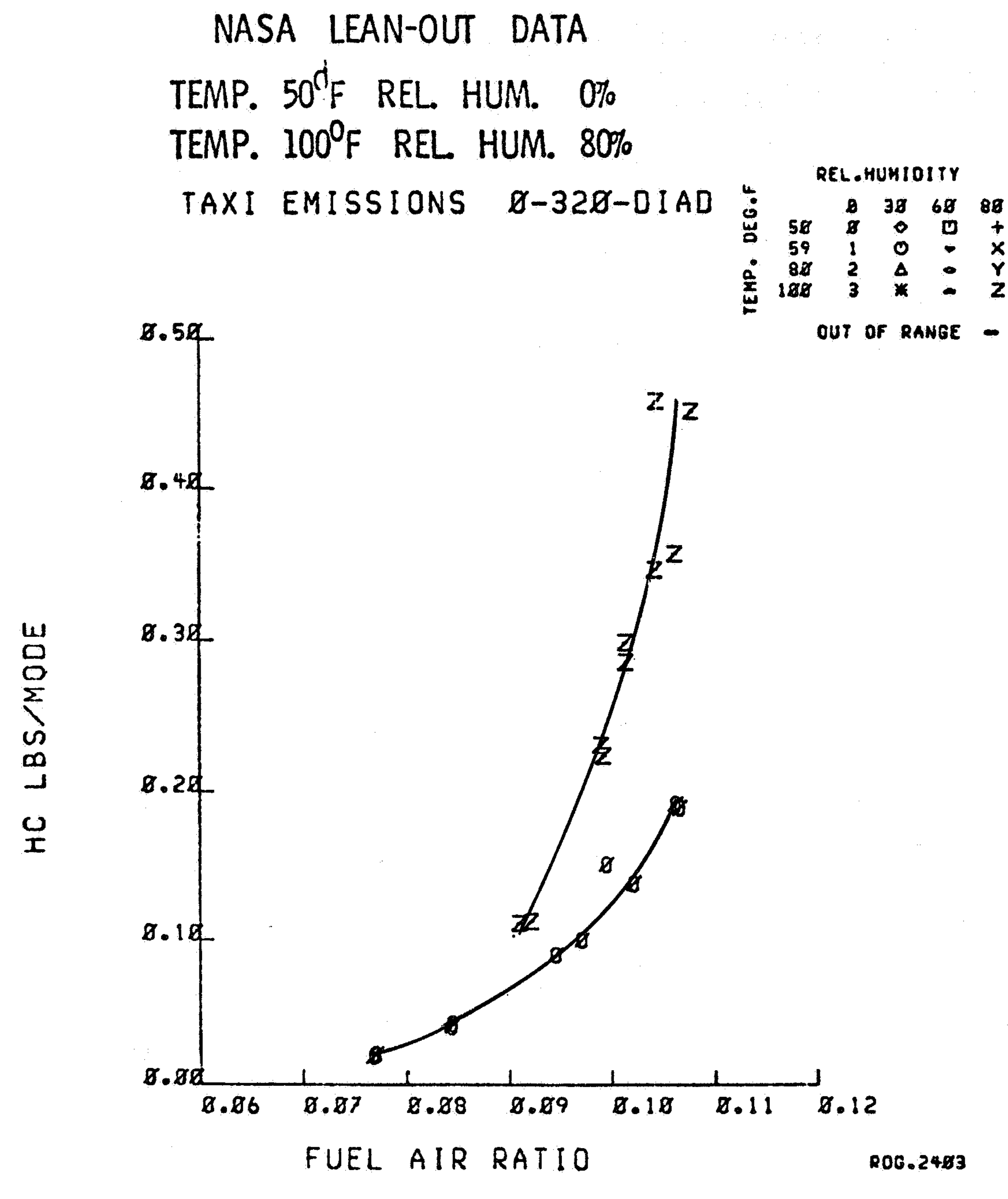

NASA LEAN-OUT DATA
TEMP. 50°F REL. HUM. 0%
TEMP. 100°F REL. HUM. 80%
TAXI EMISSIONS Ø-32Ø-DIAD
REL.HUMIDITY
TEMP. DEG.F
Ø 3Ø 6Ø 8Ø
5Ø Ø ◇ ☐ +
59 1 O ✦ X
8Ø 2 Δ ◆ Y
1ØØ 3 ✱ ▲ Z
OUT OF RANGE
HC LBS/MODE
Ø.ØØ
Ø.1Ø
Ø.2Ø
Ø.3Ø
Ø.4Ø
Ø.5Ø
Ø.Ø6
Ø.Ø7
Ø.Ø8
Ø.Ø9
Ø.1Ø
Ø.11
Ø.12
FUEL AIR RATIO
ROG.24Ø3

Figure 5-14

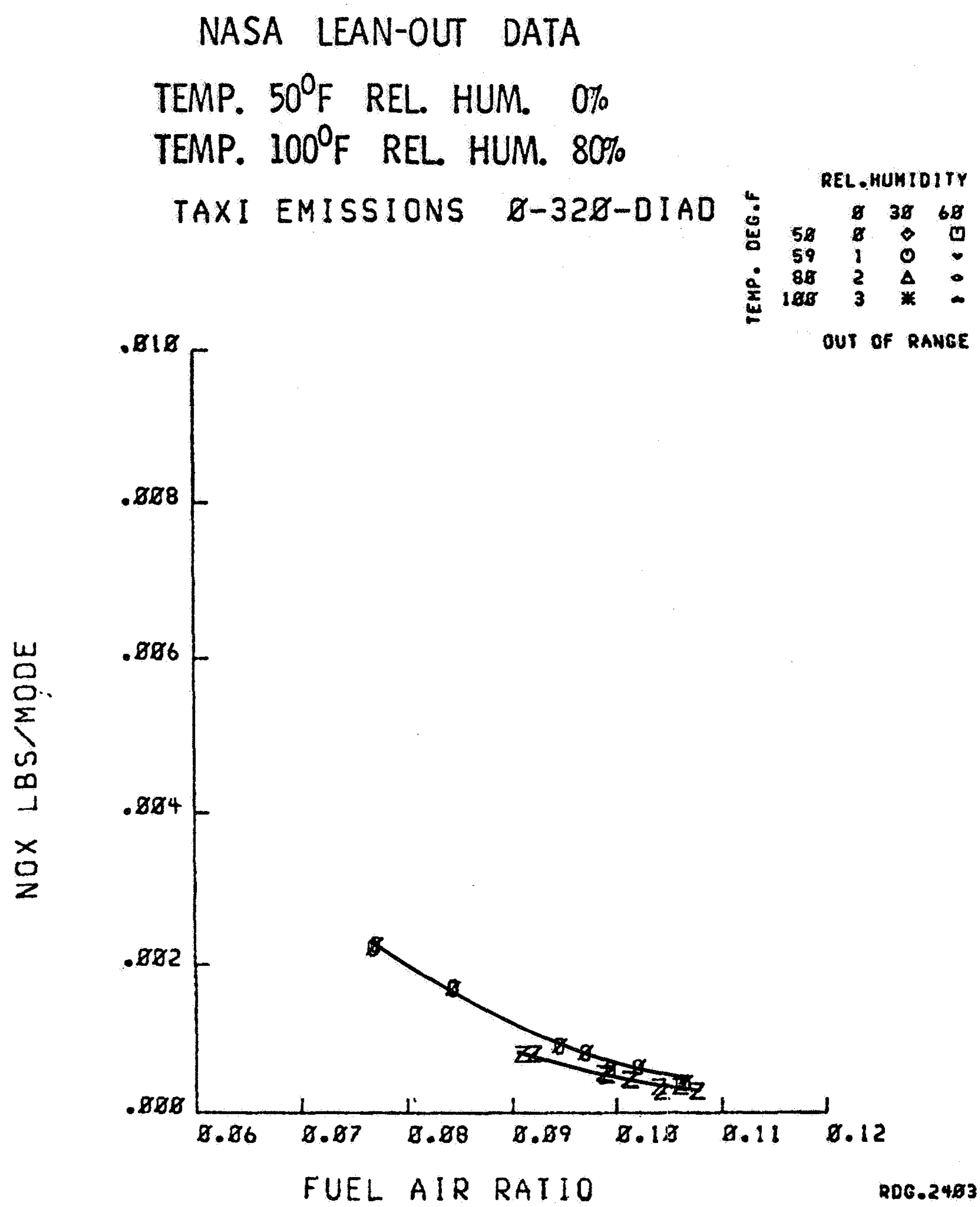
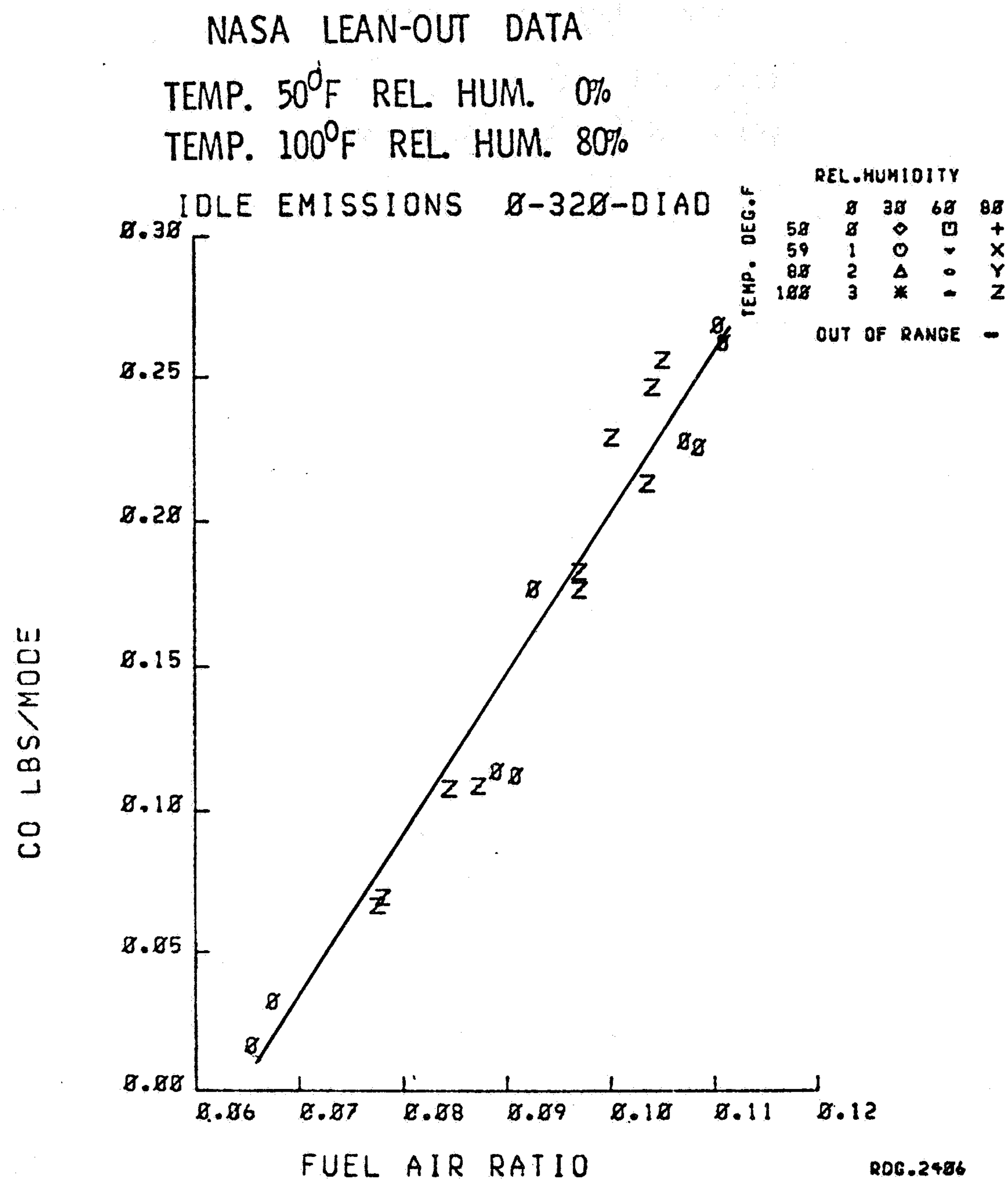
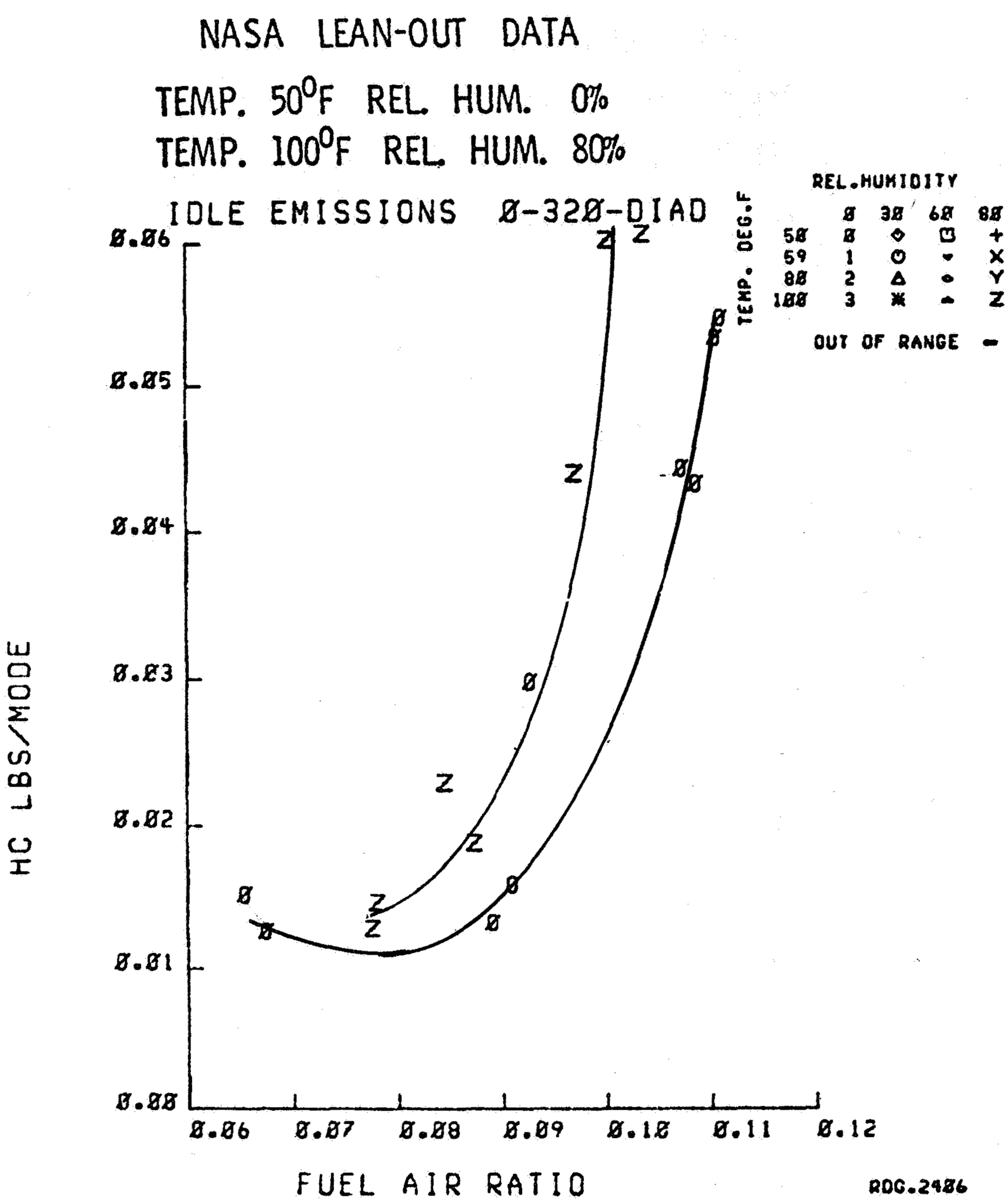

NASA LEAN-OUT DATA
TEMP. 50°F REL. HUM. 0%
TEMP. 100°F REL. HUM. 80%
TAXI EMISSIONS Ø-32Ø-DIAD
REL.HUMIDITY
TEMP. DEG.F
Ø 3Ø 6Ø 8Ø
5Ø Ø ◇ □ +
59 1 ○ X
8Ø 2 △ Y
1ØØ 3 ✳ Z
OUT OF RANGE
.Ø1Ø
.ØØ8
.ØØ6
.ØØ4
.ØØ2
.ØØØ
NOX LBS/MODE
Ø.Ø6 Ø.Ø7 Ø.Ø8 Ø.Ø9 Ø.1Ø Ø.11 Ø.12
FUEL AIR RATIO
RDG.24Ø3

Figure 5-15



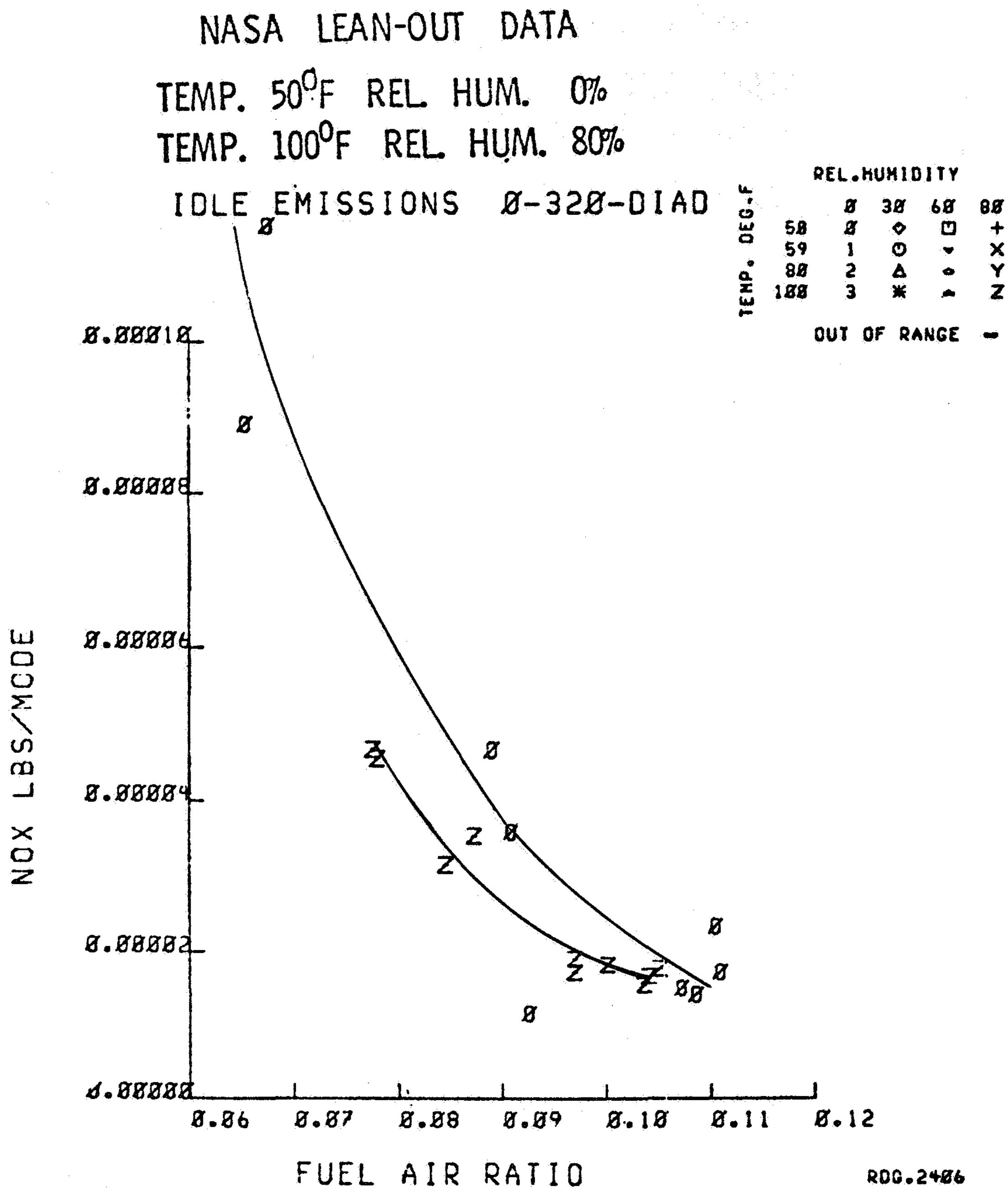
NASA LEAN-OUT DATA
TEMP. 50°F REL. HUM. 0%
TEMP. 100°F REL. HUM. 80%
IDLE EMISSIONS Ø-32Ø-DIAD
CO LBS/MODE
FUEL AIR RATIO
TEMP. DEG.F
REL.HUMIDITY
OUT OF RANGE
RDG.24Ø6

Figure 5-16



NASA LEAN-OUT DATA
TEMP. 50°F REL. HUM. 0%
TEMP. 100°F REL. HUM. 80%
IDLE EMISSIONS Ø-32Ø-DIAD
REL.HUMIDITY
TEMP. DEG.F
Ø 3Ø 6Ø 8Ø
5Ø Ø ◇ □ +
59 1 O • X
8Ø 2 Δ • Y
1ØØ 3 * • Z
OUT OF RANGE -
HC LBS/MODE
Ø.Ø6
Ø.Ø5
Ø.Ø4
Ø.Ø3
Ø.Ø2
Ø.Ø1
Ø.ØØ
Ø.Ø6 Ø.Ø7 Ø.Ø8 Ø.Ø9 Ø.1Ø Ø.11 Ø.12
FUEL AIR RATIO
RDG.24Ø6

Figure 5-17



NASA LEAN-OUT DATA
TEMP. 50°F REL. HUM. 0%
TEMP. 100°F REL. HUM. 80%
IDLE EMISSIONS Ø-32Ø-DIAD
REL.HUMIDITY
TEMP. DEG.F
Ø 3Ø 6Ø 8Ø
5Ø Ø ◇ □ +
59 1 O ▾ X
8Ø 2 Δ ◆ Y
1ØØ 3 ✱ ▴ Z
OUT OF RANGE —
Ø.ØØØ1Ø
Ø.ØØØØ8
Ø.ØØØØ6
Ø.ØØØØ4
Ø.ØØØØ2
Ø.ØØØØØ
NOX LBS/MCDE
Ø.Ø6
Ø.Ø7
Ø.Ø8
Ø.Ø9
Ø.1Ø
Ø.11
Ø.12
FUEL AIR RATIO
RDG.24Ø6

Figure 5-18

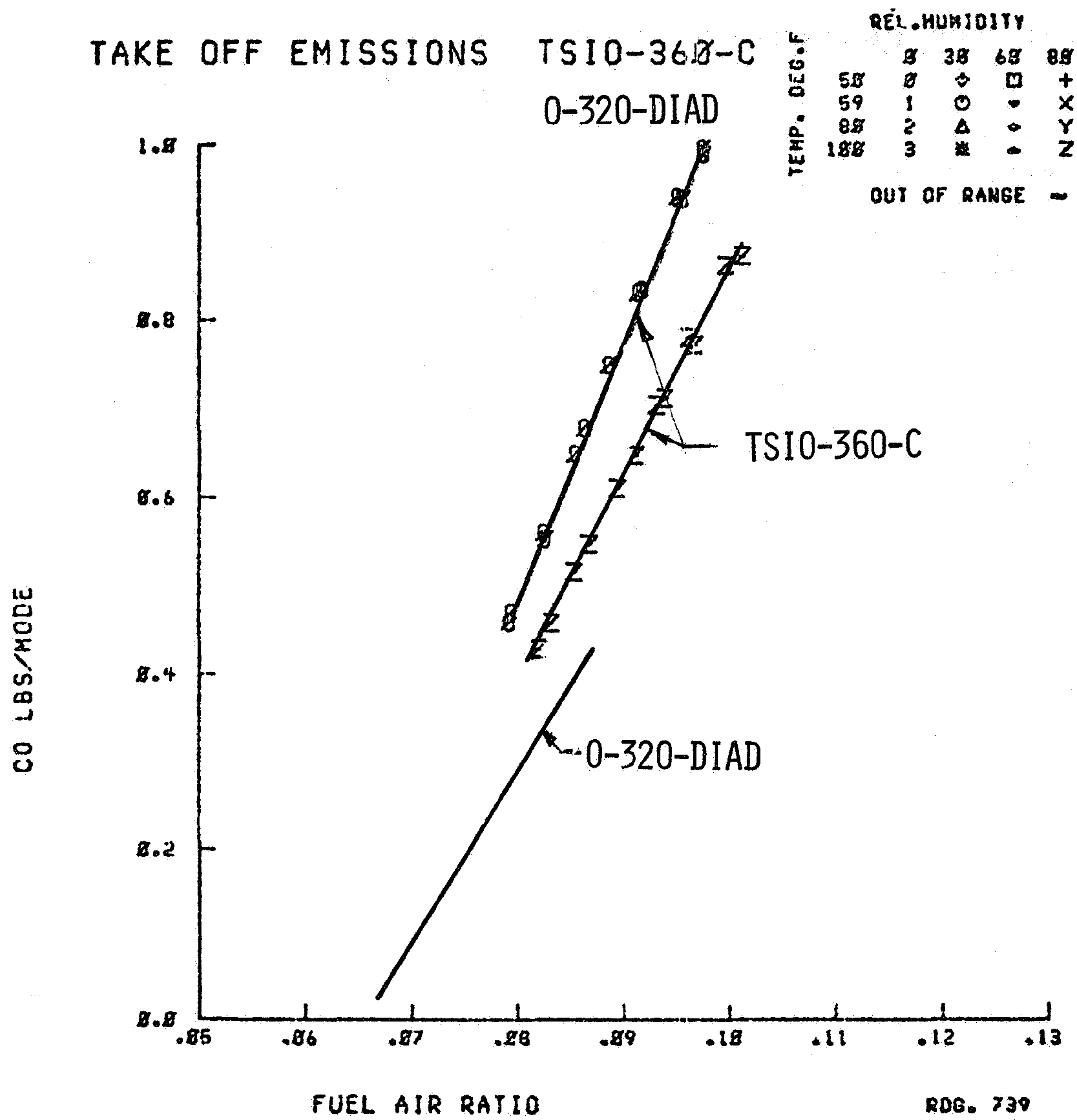

TAKE OFF EMISSIONS TSIO-360-C
0-320-DIAD
REL.HUMIDITY
TEMP. DEG.F
0 30 60 80
50 0
59 1
80 2
100 3
OUT OF RANGE
CO LBS/MODE
1.0
0.8
0.6
0.4
0.2
0.0
.05
.06
.07
.08
.09
.10
.11
.12
.13
TSIO-360-C
0-320-DIAD
FUEL AIR RATIO
RDG. 739

Figure 5-19

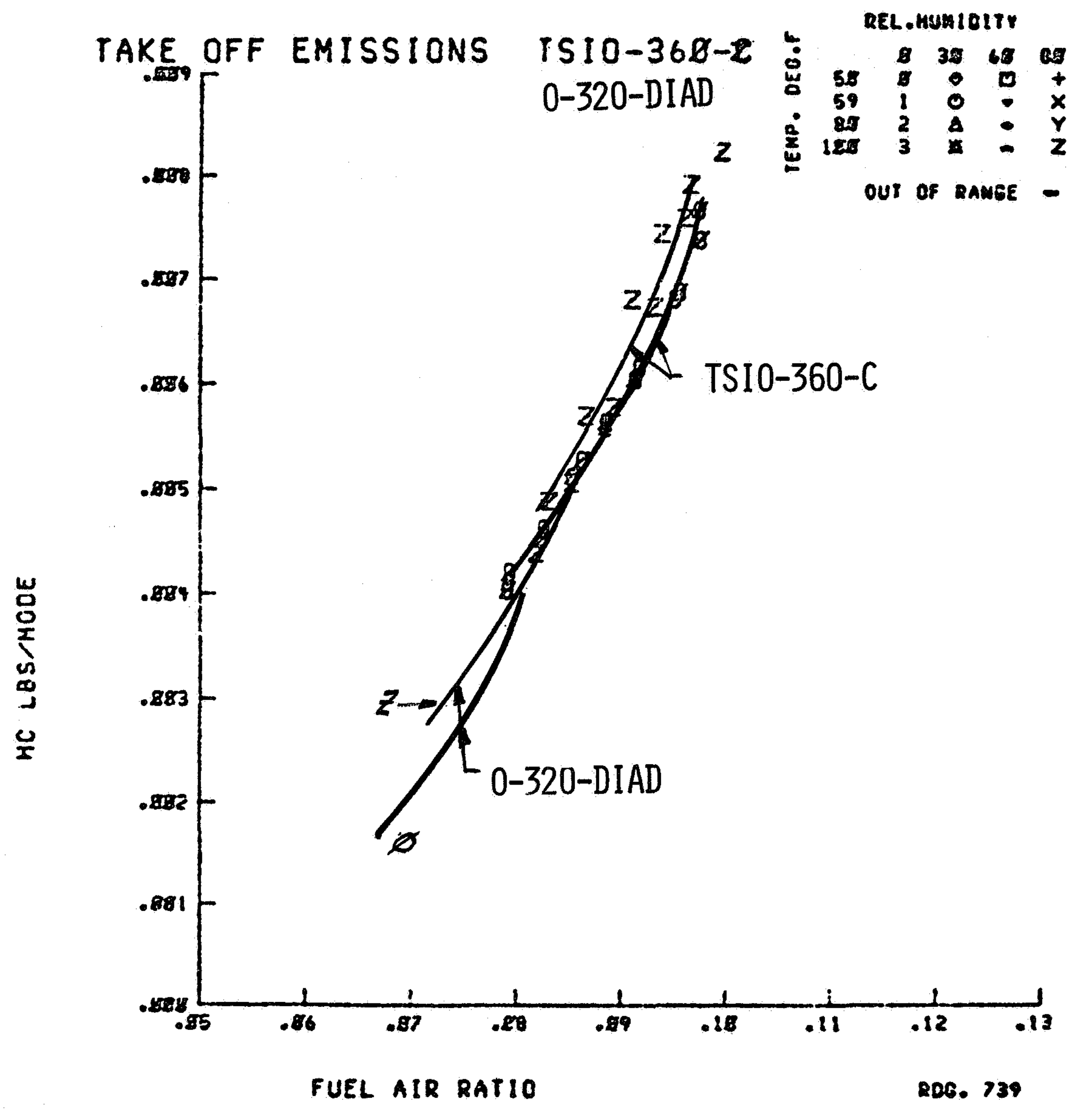
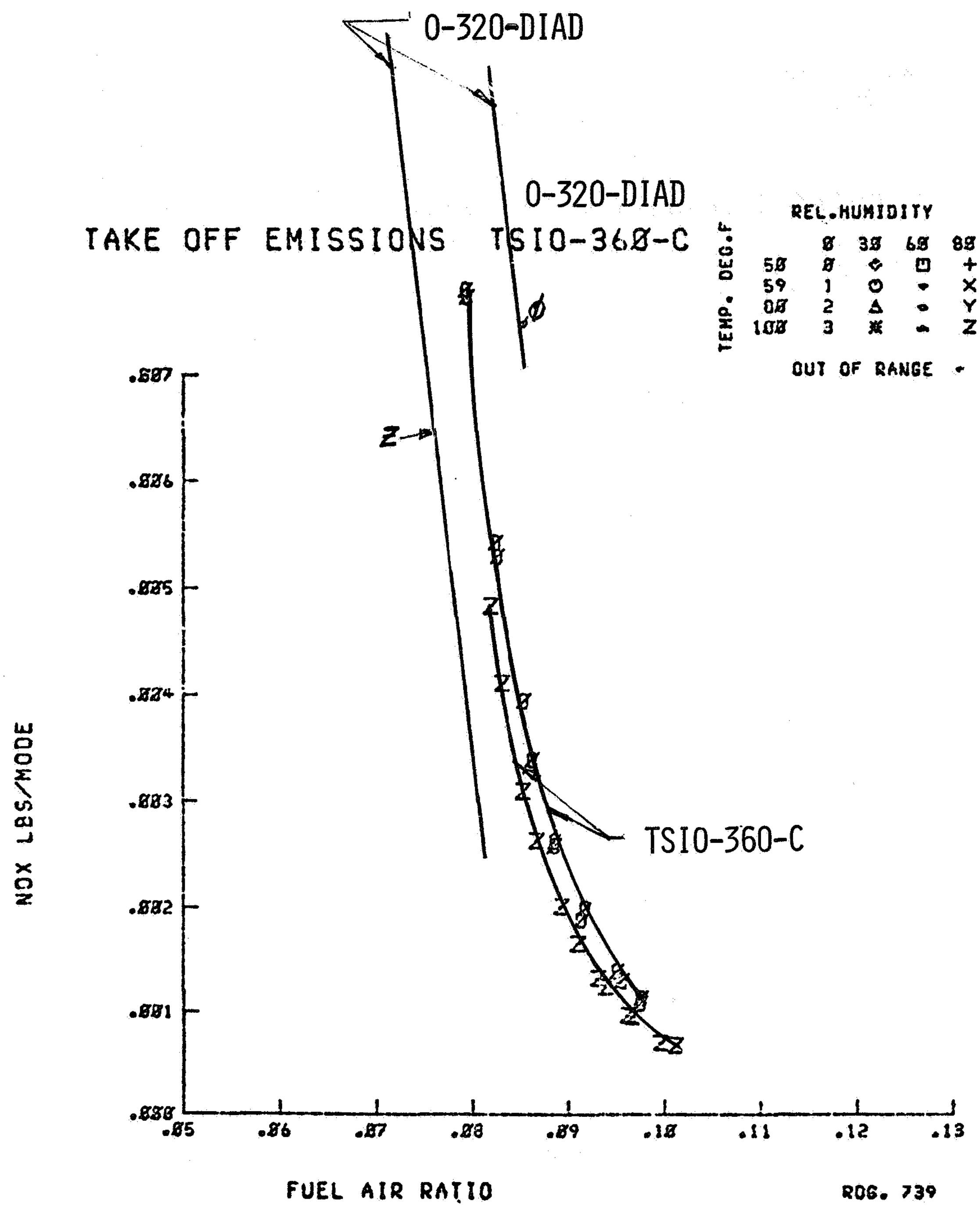
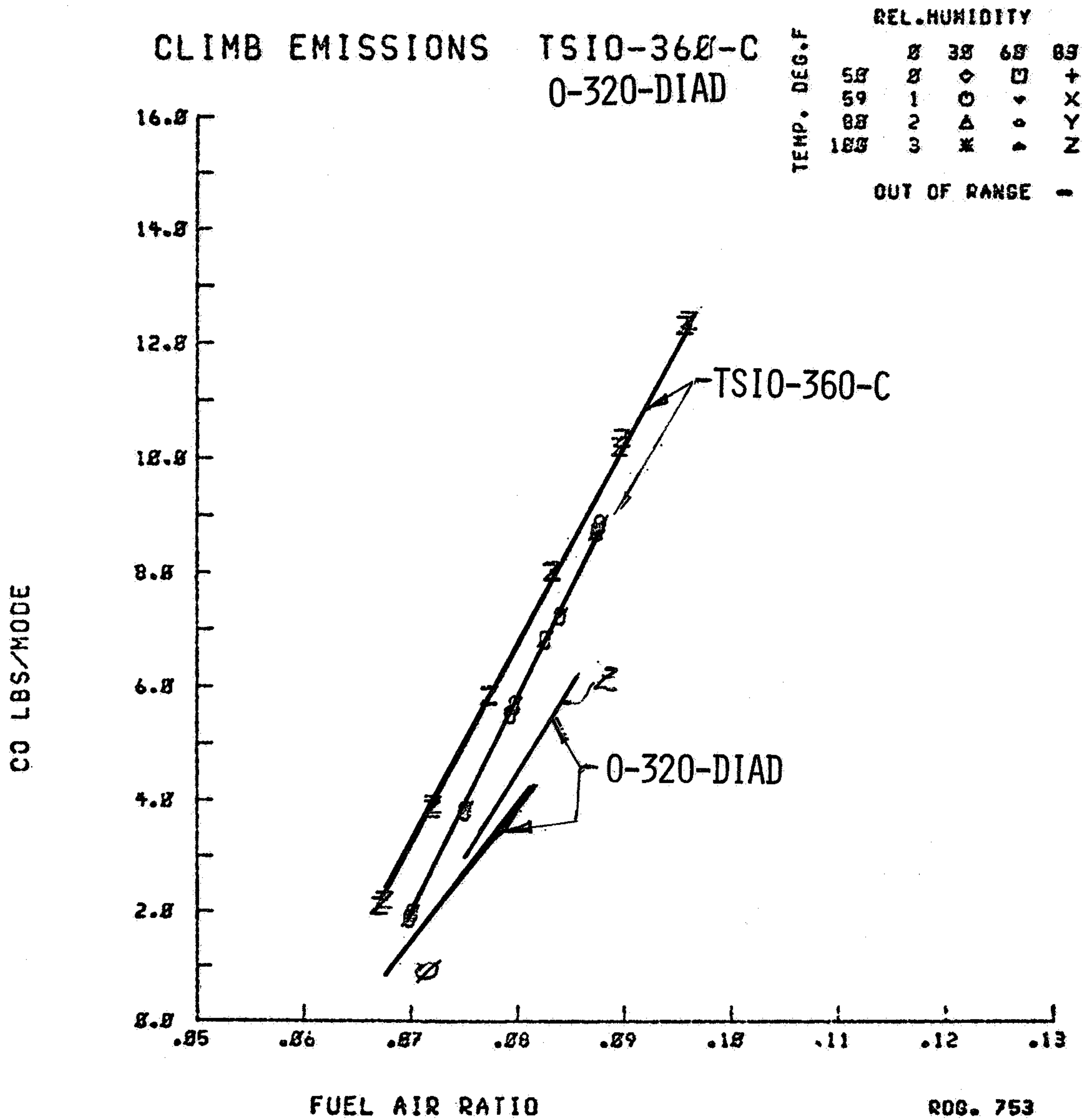

TAKE OFF EMISSIONS TSIO-360-C
0-320-DIAD
REL. HUMIDITY
TEMP. DEG. F
OUT OF RANGE
TSIO-360-C
0-320-DIAD
HC LBS/MODE
FUEL AIR RATIO
RDG. 739

Figure 5-20



0-320-DIAD
0-320-DIAD
TAKE OFF EMISSIONS TSIO-36Ø-C
REL.HUMIDITY
TEMP. DEG.F
Ø 3Ø 6Ø 8Ø
5Ø
59
8Ø
10Ø
OUT OF RANGE
TSIO-360-C
NOX LBS/MODE
FUEL AIR RATIO
RDG. 739

Figure 5-21



CLIMB EMISSIONS TSIO-36Ø-C
0-320-DIAD
REL.HUMIDITY
TEMP. DEG.F
Ø 3Ø 6Ø 8Ø
5Ø
59
8Ø
1ØØ
OUT OF RANGE
16.Ø
14.Ø
12.Ø
1Ø.Ø
8.Ø
6.Ø
4.Ø
2.Ø
Ø.Ø
.Ø5
.Ø6
.Ø7
.Ø8
.Ø9
.1Ø
.11
.12
.13
CO LBS/MODE
FUEL AIR RATIO
RDG. 753
TSIO-360-C
0-320-DIAD

Figure 5-22

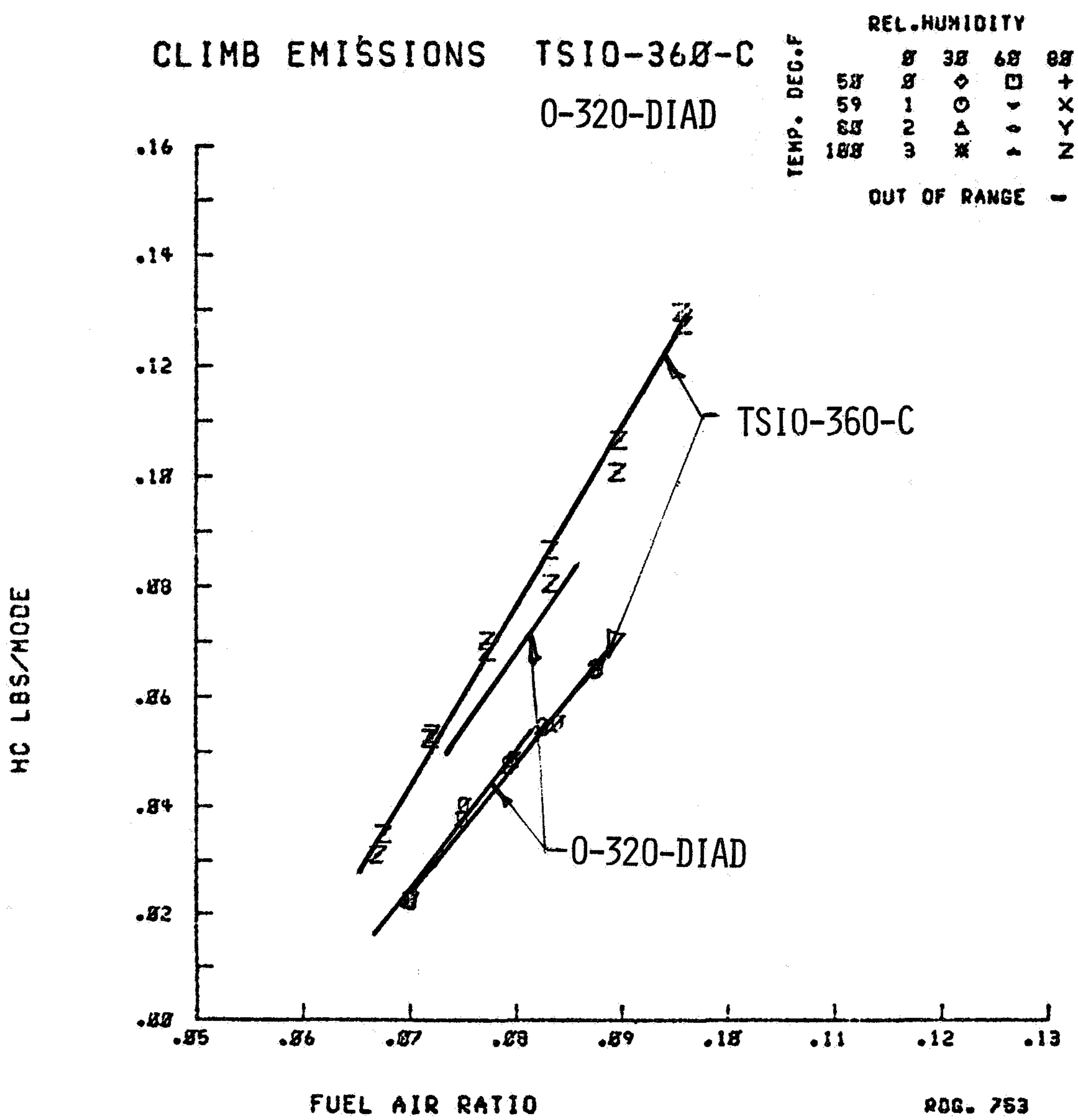

CLIMB EMISSIONS TSIO-360-C
0-320-DIAD
REL.HUMIDITY
TEMP. DEG.F
0 30 60 80
50 0 ◇ □ +
59 1 ○ X
80 2 △ Y
100 3 ✱ Z
OUT OF RANGE
HC LBS/MODE
.16
.14
.12
.10
.08
.06
.04
.02
.00
.05
.06
.07
.08
.09
.10
.11
.12
.13
TSIO-360-C
0-320-DIAD
FUEL AIR RATIO
ROG. 753

Figure 5-23

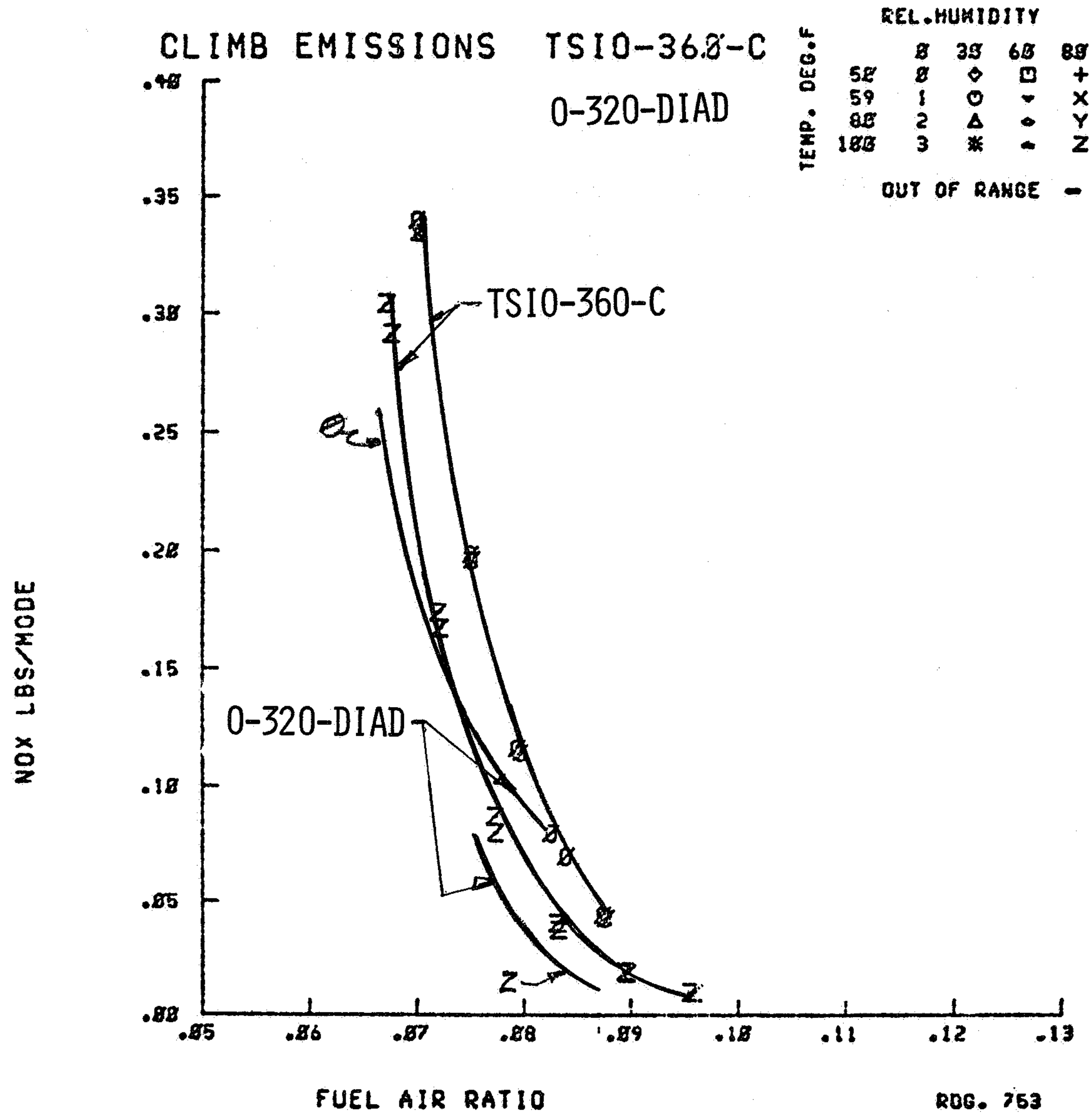

CLIMB EMISSIONS TSIO-360-C
0-320-DIAD
REL.HUMIDITY
TEMP. DEG.F
0 30 60 80
50 0 ◇ □ +
59 1 O X
80 2 Δ Y
100 3 * Z
OUT OF RANGE
TSIO-360-C
0-320-DIAD
NOX LBS/MODE
FUEL AIR RATIO
RDG. 763
.40
.35
.30
.25
.20
.15
.10
.05
.00
.05
.06
.07
.08
.09
.10
.11
.12
.13

Figure 5-24

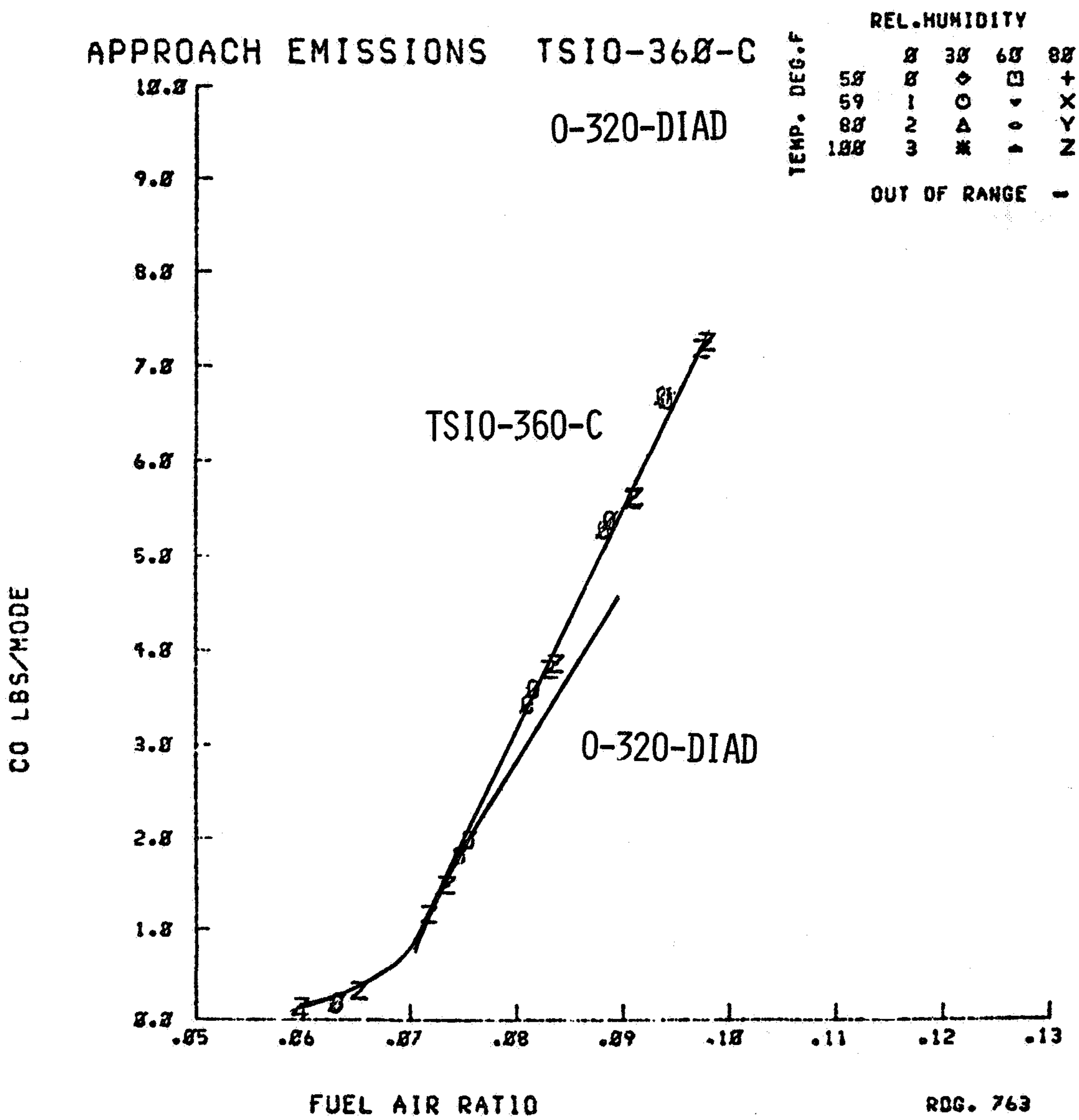
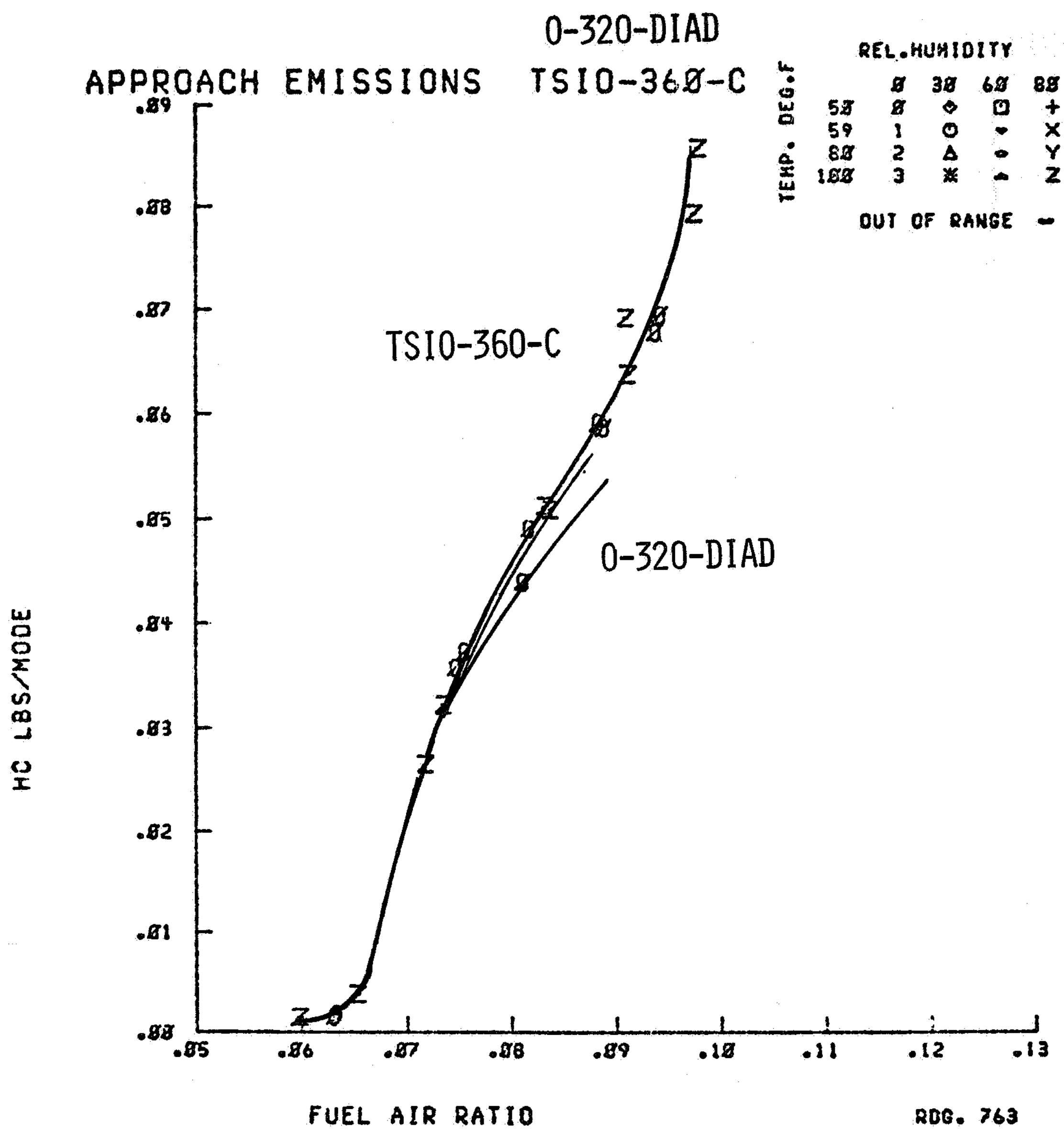

APPROACH EMISSIONS TSIO-360-C
0-320-DIAD
TSIO-360-C
0-320-DIAD
REL.HUMIDITY
TEMP. DEG.F
OUT OF RANGE
CO LBS/MODE
FUEL AIR RATIO
RDG. 763

Figure 5-25



0-320-DIAD
APPROACH EMISSIONS TSIO-360-C
REL.HUMIDITY
TEMP. DEG.F
0 30 60 80
50 0 ◇ □ +
59 1 O ▾ X
80 2 Δ • Y
100 3 ✻ ▴ Z
OUT OF RANGE ▬
TSIO-360-C
0-320-DIAD
HC LBS/MODE
.09
.08
.07
.06
.05
.04
.03
.02
.01
.00
.05 .06 .07 .08 .09 .10 .11 .12 .13
FUEL AIR RATIO
RDG. 763

Figure 5-26

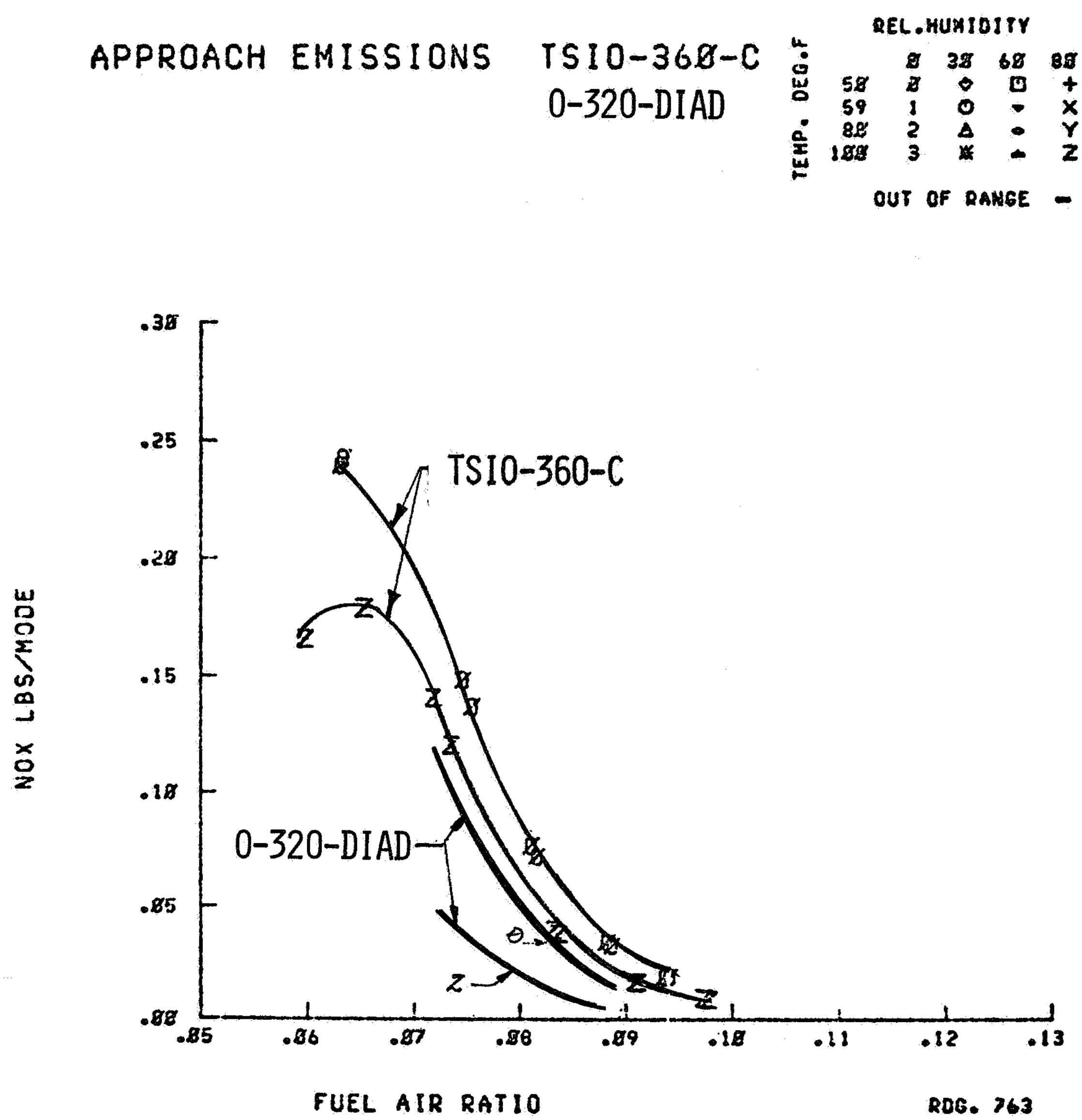

APPROACH EMISSIONS TSIO-360-C
0-320-DIAD
REL.HUMIDITY
TEMP. DEG.F
0 30 60 80
50 0 ◇ □ +
59 1 O X
80 2 △ Y
100 3 Z
OUT OF RANGE
NOX LBS/MODE
.30
.25
.20
.15
.10
.05
.00
.05
.06
.07
.08
.09
.10
.11
.12
.13
TSIO-360-C
0-320-DIAD
FUEL AIR RATIO
RDG. 763

Figure 5-27